An Interpretation of Paradigmatic Morphology

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Declaration

I declare that this thesis has been composed by myself and that the research reported therein has been conducted by myself unless otherwise indicated.

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Edinburgh, 1st May 1990

Abstract of Thesis

The thesis has as its goal the extension of current approaches in the description of natural languages, based on logics of partial information, to the area of morphology. I review work in a number of areas which may inform the study of morphology. I define a system for the representation of lexical and morphological information similar in descriptive aims to the system of *Word and Paradigm* (WP) morphology developed by Matthews, although somewhat different in technical details. I show that this system has a simple mathematical structure and indicate how it is related to current proposals in the field of feature value logics for linguistic description. The descriptive use of the system is demonstrated by an analysis of verbal paradigms from Latin.

The attested shortcomings of WP are reanalysed in the light of the formalization developed above, and I show that, contrary to previous claims, the structures developed for the formalization of WP may be both adequate for describing the morphology of non-inflecting languages and concise in so doing. These assertions are supported by sample analyses of the morphology of Turkish, taken as an exemplary agglutinating language, and of Semitic.

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Chapter 1

Preliminaries

1.1 Aims of the Thesis

The thesis has as its goal the extension of current approaches in the description of natural languages, based on logics of partial information, to the area of morphology. I define a system for the representation of lexical and morphological information similar in descriptive aims to the system of *Word and Paradigm* (WP) morphology presented in Matthews (1972), although somewhat different in technical details. I show that this system has a simple mathematical structure and indicate how it is related to current proposals in the field of feature value logics for linguistic description. The descriptive use of the system is demonstrated by an analysis of verbal paradigms from Latin.

The attested shortcomings of WP are reanalysed in the light of the formalization developed above, and I show that, contrary to previous claims, the structures developed for the formalization of WP may be both adequate for describing the morphology of non-inflecting languages and concise in so doing. These assertions are supported by sample analyses of the morphology of Turkish, taken as an exemplary agglutinating language, and of Semitic.

In presenting this description of lexical items and their morphological behaviour, there are two major points of reference. The first is the notion of Paradigmatic Morphology. Our interest here arises from the fact that the concept of 'paradigm' has a long history in linguistics, and, as discussed in Section 2.1.2, still appears to have a place within the range of constructs that are appealed to in linguistic theory.

The second point of reference is the debate in linguistics about the nature of exceptions, that is whether exceptions to a linguistic rule are essentially trivial or whether they are amenable to a more interesting treatment. This debate is considerably older than modern linguistics and can be related to the controversy between the analogist and anomalist schools, as discussed by Lyons (1968, pp6–8) and reviewed in a more general form by Robins (1988). The anomalist would hold that apparent regularities in natural language are in fact accidental, whereas the extreme analogist would claim that it is the exceptions to linguistic rules which are accidental and trivial. As is usual in debates of this kind, neither side can be shown to be wrong, either by arguments of principle or by overwhelming empirical evidence. The anomalist can point to the idiosyncratic distribution of particular lexical items, while the analogist can counter by showing that there is still substantive content to the notions that subclassify such items. The modern version of this debate can be seen clearly in the development of theories of generative grammar from Chomsky (1957) onwards. In its original conception, the theory laid considerable emphasis on notions of canonicality, with such concepts as *kernel* sentences. Any instances of defective distribution were taken to be the realm of less important areas of the theory. However, it was fairly quickly realized that an important set of phenomena in natural language were most appropriately considered to be lexical in nature, and best described by the use of lexically governed transformations (cf. Lakoff 1970, Ch. 4), in the sense that their appearance is tied to some particular lexical item. Clearly, the solution to such dilemmas is to accept the evidence adduced by both parties, while rejecting the conclusions they draw from it. This thesis follows the work of Evans and Gazdar (1989a,b) in showing that there are indeed ways of proceeding in linguistic description that allow the reconciliation of these two viewpoints.

1.2 On the Interpretation of Grammatical Formalisms

There are at least two extreme views that one may take in stating what the ultimate import is of the statements one makes in linguistic description. On the one hand, one might claim that the statements are framed in a restrictive system which reflects inherent properties of natural language, and that the notion of "possible human language" is explicated by the sum of all consistent sets of statements in that system. This is essentially the position taken by Chomsky (1965, 1981, 1986), Gazdar (1982), Gazdar *et al* (1985) and by many other researchers in linguistics. On the other hand, one may take the methodological position that the language in which one frames descriptive statements does not have a privileged status with respect to the notion of "possible human language". If one believes there are substantial invariant properties of natural language, these are encoded in the forms of axioms with which any statement in the system must be consistent. Such an approach is clear in the work of Pollard and Sag (1987) and made explicit by Shieber (1988) and, for somewhat different purposes, by Jurie and Bès (1989).

I do not bring this point up in order to argue in detail for one position or the other, as that topic requires a more detailed exposition than there is space to give it here. Rather, I would like to emphasize that the methodology taken in this thesis follows the second position rather than the first. The reasons for this are largely pragmatic. In showing that it is possible to give a formal, generative interpretation of statements in a paradigmatic form, I must more or less necessarily diverge from existing systems for morphological description which have rejected the paradigmatic mode of description as informal or cumbersome. A further reason is that the technical devices I shall make use of originate with mathematics and computer science, in which fields generality is to be preferred over solutions for the special case (cf. Shieber 1985).

My concern here is then with the elaboration of a system which allows us to describe those aspects of the domain we deem to be important, while minimizing assumptions that impose extra structure on that domain. If there are further constraints on the objects we wish to describe which represent interesting generalizations about the domain, we must encode these axiomatically (and any explanation for the form such axioms take must be sought elsewhere—it is not given by the descriptive system itself).

In the light of this position, one question that becomes of great interest is the extent to which devices introduced in the description of some linguistic phenomenon or in some linguistic theory may be related to devices proposed in other linguistic theories. The adoption of a formally specified framework makes it easier to determine whether this situation holds. Again following Shieber (1988), a positive answer to such a question allows us to be certain that an analysis proposed in one theory may be adopted by another. In Chapter 4, we shall be interested precisely in the way statements in the framework of Paradigmatic Morphology may be related to statements within other formalisms.

In this context, it is worth contrasting the position I shall take with that implied by Anderson (1988b, p541):

> Linguistics is by now a highly formal field, with rather explicit computations corresponding to most of its basic constructs. Central areas of the field ... are routinely presented in the form of explicit algorithms when they are to be made precise. Our very notion of what constitutes a possible ... rule, grammar, constraint, etc., is usually formed on the basis of its translation into some explicit procedure for effectively computing the nature of some class of linguistic objects.

I would suggest that Anderson's statement is somewhat at odds with the actual state of affairs. In particular, I would argue that work in most grammatical formalisms, including LFG (Kaplan and Bresnan 1982), GPSG (Gazdar *et al* 1985), HPSG (Pollard and Sag 1987), CCG (Steedman 1985) and GB (Chomsky 1981, 1986), currently takes the view that linguistic objects should be characterized in a way that makes no commitment as to concrete procedures that might compute relations that hold between linguistic objects. That is, one gives a logical, rather than an algorithmic or *procedural* characterization of well-formedness. While we may well require the existence of an algorithm which performs the appropriate computations to determine whether, say, a sentence is grammatical according to some linguistic theory, its operation is essentially irrelevant to the characterization of well-formedness. This more abstract perspective makes it easier to compare proposals, both in terms of the devices invoked and in their relative coverage, and to determine the internal consistency of the proposals.

As a consequence of the position taken above, questions such as the learnability or predictions of diachronic behaviour implied by the formalisms are of less methodological import than in more general linguistic discussion. Despite the temptation to indicate the implications of the formalism developed below in these areas, space does not permit of an adequate treatment. These comments notwithstanding, it is of course incumbent on me to indicate those points at which a particular technical decision has some empirical content, and when my proposals are borne out or thrown into question by some phenomena of natural language.

1.3 Orthography and Phonology

In the formalization I will present below, the construction of partially described strings is used to represent the orthographic behaviour of words, in a manner very similar to Matthews (1972, p164). I will make exactly the same caveat as that author with respect to the appropriateness of orthographic representations in the description of the phonology of natural language, namely that it is possibly the case that an approach which sets up phonological units, such as phonemes, with properties closely related to those of orthographic elements, such as characters, may fail to give an insightful characterization of phonology. Work in the fields of prosodic phonology (Firth 1948) and, more recently, non-linear phonology

(Goldsmith 1976, McCarthy 1981, Bird and Klein 1990 and many others) suggests strongly that appropriate models of phonology take as their basis elements of varying sizes. Hudson (1986) points out that the need to have an orthographic rendering of our formal descriptions may be positively misleading—orthographic concatenation imparts to descriptions a linearity which may be too specific for a useful characterization of phonological information. The model presented below is strictly linear and, for this reason, I emphasize that the descriptions given below are strictly limited to the orthographic domain. This position allows us to ignore details in the description of phonological structure which would take us too far afield from the current topic. I return to the question of the adequacy of this position in my conclusions.

1.4 Derivation and Inflection

The distinction between derivational and inflectional morphology is well accepted, but as with many other cases of terminological agreement in linguistics, a satisfactory formal definition of the distinction is very difficult to produce. I agree with Hoeksema (1985, p15) that Anderson's (1982) discussion is one of the clearest from the point of view of delimiting the area to be covered by the distinction. However, I am less inclined to think that Anderson's proposal (1982, p587), "Inflectional morphology is what is relevant to the syntax" is sufficient to the task of providing a useful definition, even despite that author's note that this definition is to be construed in an entirely theory-internal sense (Anderson uses a version of Chomsky's (1981) Government and Binding theory (GB)). He suggests that we might be able to delimit a set of "relevant" syntactic properties, if we ignore those specifically to do with "lexical insertion and related subcategorization information". Anderson's definition needs substantial revision if one has a preference for lexicalist grammatical formalisms such as Categorial Grammar (Steedman 1985, Zeevat *et al* 1987) and Head-Driven Phrase Structure Grammar HPSG (Pollard and

Sag 1987). In these cases, the bulk of information is associated with individual lexical entries—the possibilities of syntactic combination are described by a small number of highly schematic relations between syntactic categories or featural descriptions thereof. Due to their schematic nature, syntactic rules are unlikely to make any reference whatsoever to the features that determine the behaviour of, say, agreement in some language. These features are assumed to be lexically given and their effect is determined entirely by the assignment of features to other lexical items and, therefore, only indirectly by rules of syntax.

Fortunately, for the purposes of this thesis, I can adopt a pragmatic position. I will not attempt to formulate a definition of the features that are, in an appropriate sense, "relevant to the syntax", and all of the examples I discuss below are, by consensus, inflectional.

1.5 Linguistic methodology in a nonmonotonic setting

In standard presentations of formal languages, for instance Aho and Ullman's (1972) discussion of context-free grammars, it is supposed that there is a notion of *derivation*. That is, given some sequence of syntactic categories and a rule whose right-hand side matches that sequence, we may derive a constituent corresponding to the rule's left-hand side. The string set or language generated by the grammar is then the closure of the set of rules. We may view the relation **generates** as holding between the grammar and elements of the string set. If we add some new rule to extend the phenomena described by the grammar, we are likely to increase the size of the string set. More specifically, any sentence previously analyzed by the grammar will be analyzed by the extended grammar. From a logical perspective, we may view the set of rules as a set of statements, to be read disjunctively, which allow us to infer grammatical sentences as theorems. Adding a new element to the set of statements does not invalidate any inference that might have been made from that set. This property of preserving inferences is termed *monotonicity* and is discussed in a more general setting by Shieber (1986b) and Moshier and Rounds (1987); see also Section 2.3.1 below).

In many proposals for linguistic formalisms, the question arises of alternative conceptions of the process of derivation or the content of the notion **generates** for a linguistic system. This question has to be addressed in any situation where a grammar generates some object, or allows some derivation, but where we wish for some other reason to prohibit this derivation. Our main concern in this thesis will be with situations of this form in the area of morphology, in which the addition of a statement may invalidate a "previously allowed" derivation and where the application of a rule may "remove" or "defeat" information associated with some linguistic object, but others are easily found in many other areas of linguistic description. Chomsky (1981, 1988) provides us with two examples from the area of syntax. First, the "Avoid Pronoun" principle (Chomsky 1981) is invoked to rule out the second of the sentences below:

(1) a John wants to go
    b *John wants himself to go

The force of Chomsky's principle is that, as the only relevant difference between (1a) and (1b) is the appearance of the pronoun *himself* in (1b), the second sentence is to be ruled out.

Chomsky (1988) proposes that there is a "preference for shorter derivations". Note that *shorter* is in this case a technical term—it does not correspond simply to the respective length of competing derivations. Such operations are "applicable where necessary". He gives the example of do-support, where the auxiliary *do* may be inserted into a structure only if failure to do so would result in an ill-formed structure, say in the case where there is no legal position for tense to be expressed. In this case, we effectively allow two possible derivations, but prohibit one of them in the case where application of some rule is possible but not necessary. This is illustrated in (2), where (2c) represents the "possible but not necessary" case:

(2) a John do+es not go
b John goes
c John _+es go

From (2c), we might generate either ***John goes*** or ***John does go***, and it is the second of these we want, in the general case, to rule out.

In Chapters 2 and 3, I will address two questions.

- What becomes of the notion of "prediction" in a nonmonotonic setting?

- What is the nature of a linguistic exception and, more precisely, what systems capture the behaviour of exceptions?

As hinted at in Section 1.1, there are two extreme positions with regard to the second question. One view would hold that languages have a fundamentally regular structure, and that the statements one makes in description are lawlike. Exceptions to these statements, where they are found, are uninteresting and unworthy of attention. The Bloomfieldian description of the lexicon seems to have very much this quality: "The lexicon is really an appendix of grammar, a list of basic irregularities" (Bloomfield 1933, p274). This view of the notion of exception may be traced through Chomsky and Halle (1968) to Chomsky (1988).

On the other hand, one might maintain that, while there are certainly uninteresting exceptions, there are other *subgeneralizations* which are not adequately captured in a setting which assumes a single rule to handle a particular phenomenon. Informally, there are "good reasons" why some exception to a rule is found. In other words, there is structure, as proposed by Chomsky in the cases cited above, in the exceptions that we find—it is possible for exceptions also to be lawlike. Bloomfield (1933, p174) recognizes that this situation may hold, and uses the term *irregular analogy* in this connection.

Obviously this discussion is closely connected to that about the nature of "productivity". In what follows, I shall adopt very much the position of Hoeksema (1985), Anderson (1988a, p186-187) and Bauer (1988, n.d.), amongst others, in claiming that, while morphological productivity may appear from a statistical perspective to be a matter of degree, this is because the preconditions for a particular morphological operation may be arbitrarily specific. That is, a rule for forming, say, de-adjectival verbs may be constrained to apply only to a subset of adjectives on the basis of their phonological form. (Anderson cites analogous cases described by Siegel 1974). The limiting case is that in which a particular rule is applicable to just a single lexical item, for example, the suffix "ric" in "bishopric" (cf. Bauer, n.d.). Once appropriate restrictions on the application of a rule have been determined (at least in the case of inflectional morphology), the relevant rules may be taken to be fully productive.

1.6 Summary of the Remainder of the Thesis

I close this introductory chapter with a brief summary of the remainder of the thesis. I will examine the following questions:

- What systems are appropriate for the description of orthographic objects within logically based linguistic formalisms?
- What systems are appropriate for the description of the morphology of natural language?
- What does it mean to say that a lexical item is marked as irregular in the lexicon?

Chapter 2 is a survey of related work from two perspectives. I first review the treatment of morphology within linguistics and computational linguistics, examining the motivation for a number of descriptive mechanisms. I then turn to a consideration of the formal devices which allow us to capture the behaviour of these descriptive mechanisms, drawing on work in the areas of feature value and nonmonotonic logics.

In Chapter 3, I make use of these devices to develop a formal reconstruction of the traditional notion of a morphological paradigm. A simple analysis of English is developed. Logical properties of these systems are examined in relation to the work discussed in Chapter 2.

Chapter 4 then considers how descriptions made using paradigmatic devices may be related to mechanisms proposed for the treatment of non-inflecting languages. If the comments there are of any merit, they are at least suggestive of how we might work towards the description of typologically different languages within a unified framework, and thereby arrive at a more flexible typology and more insightful characterizations of the various morphological systems evidenced in the languages of the world.

Chapter 5 is a critical appraisal of the content of this thesis.

There are two appendices. Appendix A contains a substantial paradigmatic analysis of Latin verbal morphology as an illustration of the paradigmatic approach. Appendix B discusses the computational interpretation of the framework I propose.

An analogy may here help to clarify my intent and the overall design of this thesis. The formal material discussed in Chapter 2 may be thought of as bricks and mortar, things of general utility. Chapter 3 is then an essay in a particular style of architecture, a way of arranging smaller units for functional and aesthetic purposes. Chapter 4 attempts to broaden this perspective by showing that the methods of construction appropriate for one style of architecture may be used in other settings. The question to be addressed is then to what extent any differences in style are superficial and may be supported by the same bricks and mortar.

The following general convention applies in what follows. Many of the concepts discussed below make reference to some notion of *ordering*. Having defined some relation of ordering to hold between two objects, say $A > B$, I will assume the alternative $B < A$ also to be defined, and likewise for $\geq$ and $\leq$. Otherwise, my notational usage, for operations such as conjunction, set construction *et cetera*, will be standard and explicated in the text below where necessary.

Chapter 2

Aspects of Morphological Theory

In this chapter, I review work in a number of disciplines which impinge on the study of morphology and the formalization of frameworks for morphological description. Central to the first part of my presentation of this material will be work in linguistics and computational linguistics on frameworks for morphological analysis. Rather than attempt an overarching summary of the large body of work in this area, I shall in Sections 2.1 and 2.2 review developments in these two fields germane to the topics to be discussed in Chapters 3 and 4. In discussing the representation of morphological information, the logical behaviour we require of systems for representing such information must also be considered. The formal basis of grammatical frameworks and extensions required for the description of morphological information is therefore discussed in Section 2.3. Finally, many proposals for the treatment of morphology rely on formalisms which are *nonmonotonic* (see Section 2.3) and, in Section 2.4, I review existing proposals for the relaxation of monotonicity in the systems of Section 2.3 and some important concepts from the area of nonmonotonic logics.

I take the scope and content of morphology to be essentially as defined by Matthews (1974, see also Lyons 1968). I therefore recognize a tripartite distinction between *word-form*, *lexeme* and *word*. *word-form* refers to a representation of orthographic (or phonological) content, as in "the word-form *loves* contains five characters" or "is monosyllabic and contains a short vowel". The *lexeme* is the fundamental unit of analysis within this tradition, and so the word-form *loves* is said to be a form of the lexeme LOVE. A lexeme such as LOVE may be thought of as a name for one of a set of objects, these objects representing the set of lexical elements recognized by the grammar. Finally the term *word* refers to a complex of information; in Matthews' construal, a word is a lexeme which is qualified *morphosyntactically*. For instance, *dogs* is the word-form corresponding to the qualification of the lexeme DOG by the morphosyntactic information "plural". The aim of morphology is then to characterize the relations that hold between word-form, lexeme and word. To put things more concretely, we are interested in showing how the orthographic (or phonological) form presented by some element which we recognize as basic in some sense varies, according to specifications that we assume to be associated with that element on the basis of syntactic distribution.

From this formulation of the goals of morphology, it follows that an adequate theory of morphology should allow for the description of information to do both with the form of words and with morphosyntax. In the formal development in Sections 3.1.1, I offer distinct systems for each of these modes of description. The first of these characterizes orthographic expressions as partially specified strings, while the second treats morphosyntactic information as expressions in propositional calculus. This division is essentially an aid in motivating the formal structure of these systems. It is certainly the case that a single language, capable of expressing both of these kinds of information, could be devised.

2.1 Morphology in linguistics

In this section, I review the recent history of the study of morphology and the major typological distinctions that have been proposed. I then consider some of the basic choices open to researchers in this field, concentrating on the role of rules that relate morphosyntactic specifications. Finally, I review the formalisms of *Word and Paradigm* and *Extended Word and Paradigm* morphology, which are most closely related to the formalism I shall present below.

During the first half of this century, morphology was held to be a core component of linguistic theory. By the early 1970's this interest had withered (in American linguistics at least) to the point at which it was believed that all facts of apparently morphological import were due solely to the interaction of syntax and phonology. The shortcomings of this view were pointed out by Halle (1973). Aronoff (1976) and Anderson (1982) document the resurgence of interest in morphology. I will not consider the vast body of literature produced by the American structuralists in the period 1910 to the late 1950's and well represented by the papers in Joos (1957), despite its intrinsic interest. Our reason here is that, following Matthews (1972, Ch. 6), the position of the American structuralists necessarily implies that the morphology of natural languages conforms strongly to the pattern of semiagglutinating languages. If we are interested in languages that are not of this type, this framework is insufficient to the task.

Languages show considerable variation in the type of morphological resources they call upon. In particular, the standard tripartite distinction between isolating, agglutinating and inflecting languages holds that one major variation is whether constituent morphemes appear unchanged in complex forms and, if not, whether any deformations from their citation form are of a regular or irregular nature. There are some languages which appear to conform well to the extremes of this distinction. The textbook cases are Vietnamese, Turkish and Latin respectively (Matthews 1974, p17).

Just as the distinction between inflecting and agglutinating languages has long been recognized so it has been recognized almost as long that the distinction is not hard and fast. Languages typically fail to fall strictly in one class or the other. Extreme inflecting languages are characterized by the fusion of elements representing the exponents of grammatical classes and the often suppletive relations holding between such elements. Latin usually provides the textbook example and Georgian is often cited. Extreme agglutinating languages, of which Turkish is often taken to be an exemplar, typically show no fusion of grammatical elements, but do have allomorphs of elements which may be phonologically conditioned. Given that languages in general do not conform strictly to either of these characterizations, or to that of isolating languages for that matter, we should require of our descriptive devices in morphology that they are not predisposed to the description of particular language types and that they do not give preference to the extreme language types over the more common, mixed types.

One open question in the study of morphology which I shall ignore is whether, to use Anderson's (1988a, p162) terminology, morphology should be "word-based" or "morpheme-based"—whether the fundamental units of morphology are complex in the sense described above or whether morphology should consider indivisible units and their structural arrangement. As implied by the position taken above, I shall follow the word-based approach here. Into the same camp fall workers such as Anderson, Aronoff, Matthews, and to a lesser extent, Sadock and Spencer. Structurally oriented accounts of morphology are to be found in the work of Baker, Lieber, Selkirk and Williams. I now turn to the question of the extent to which a theory that allows "transformations in the lexicon" is tenable or desirable.

2.1.1 The "atransformational" lexicon

Bresnan (1982, p20) proposes that the passive and active forms of English verbs are related in the lexicon by means of the rule (3) together with an appropriate statement of the morphological effect of the rule:

(3) $(\textsc{subj}) \mapsto \phi \; / \; (\textsc{by obj})$
$(\textsc{obj}) \mapsto (\textsc{subj})$

To gloss this statement, a lexical item which has a predicational structure that involves at least a subject and an object may be transformed into another lexical item with the same specification as before, except that the previous association between some argument position and (SUBJ) is replaced with an association between that position and (OBJ). The initial association between (SUBJ) and some argument position is either deleted or is replaced by an association between that argument position and (BY OBJ). The most important word in this paraphrase is *transformed*; the position taken by researchers in this area followed directly on from that of previous versions of transformational grammar, in that the analysis of the active-passive relation was held to involve the derivation of the structures that describe (lexical items with) passive morphology from those that describe (lexical items with) active morphology. This is parallel to the preceding, transformational view which transformed active sentences into passive ones (as in Chomsky 1957, p43). As with transformations in syntax, there are essentially no constraints on the operations that can be performed by lexical rules. We may for instance have chosen to delete all the specifications mentioned in the rule above.

Two strands of research have provided an alternative view of the relations that may obtain between elements of the lexicon. The first originated with Foley and van Valin's (1984) concept of *macrorole* and Dowty's (1989) work on the theory of thematic roles. The second strand is represented by the work of researchers such as Levin (1986), Bresnan and Mchombo (1986), Bresnan and Kanerva (1988) and Zaenen (1988). The proposal may be described by analogy to more traditional proposals in the area of lexical representation. In the tradition of work stemming from the *Sound Pattern of English* (Chomsky and Halle 1968), entries in the lexicon are conceived as being *abstract*. In particular, they are not associated with a concrete phonological representation. Rather, the phonological content is represented as some underlying form from which concrete phonological forms may be derived. The proposals under discussion here can be seen as a similar move, proposing a more abstract statement of the relation between active and passive forms, in terms of *thematic* relations such as agent and patient, rather than syntactic relations such as subject and object.

Under the name of *lexical mapping theory*, Bresnan and Kanerva (1988) propose a set of conditions which govern possible patterns of the association of thematic and syntactic relations. Briefly, syntactic functions may be classified by means of the binary features r ("thematically restricted") and o (objective). Thus, the feature $[-\ r]$ characterizes both of the functions SUBJ and OBJ. The syntactic functions associated with a verb are underspecified with respect to these features. However, principles of lexical mapping theory, such as the ***agent encoding principle***, may further specify syntactic functions. This principle states that the agent role cannot be realized as a function which is objective ($[+\ o]$), and so the agent role will always specify its syntactic function as $[-\ o]$. The specification of a verb is then determined by the interaction of its lexical specification in terms of thematic relations and the general encoding principles, possibly in conjunction with analysis of the environment in which the verb occurs. (Bresnan and Mchombo also allow some features to be assigned a value by default). Other, recent work within this general area is Sanfilippo (1990) and Whitelock (forthcoming).

For our purposes, the most important property of these systems is that they are "atransformational"—they make no use of operations which alter representations. Operations may only further specify representations. These proposals have many interesting implications for the system of morphological representation I present below and are further discussed in Section 3.1.3.

These proposals may have advantages from a formal as well as a descriptive point of view. Under the transformationalist hypothesis, one is essentially forced into the position of admitting some kind of ordering with respect to the process of derivation. The general question of the ordering of rules is discussed by Matthews (1972, Section 10.3), *inter alia*. For our purposes, we may identify two subcases of interest.

The first possibility is that any ordering produces appropriate results. This is the simplest case, as one may simply view derivability as the closure of the rule set in question. Classical "feeding" relationships between rules will be simply intrinsic—

a derivation may produce the context in which some other rule is applicable. "Bleeding" relationships do not exist, as for any pair of rules, R and R' such that application of R prevents R' from applying, there will be some derivation in the closure where application of R' is not preceded by application of R. In other words, if R' has some preconditions which are met by the specification of some item and R changes the specification of that item so that R''s preconditions are no longer met, there is still a possible derivation under which application of R does not precede that of R'. This formulation allows the possibility that two distinct orderings of rule application may give rise to distinct results.

The second possibility is that a stipulated ordering will produce the desired results. This is the classical view of "extrinsic rule ordering" (Chomsky 1965, p39f, p133f *inter alia*). Rather than allowing the unrestricted closure of some rule set, only those derivations consistent with the stipulated ordering are permitted. In the light of work such as Johnson (1972) and others, this may not present a formal problem in certain cases, as one might be able to view some process of "order-constrained" derivation as equivalent to a single, more complex process which faithfully reflects the ordering constraints. However, Johnson's results are in the very limited domain of phonological rules and may not transfer easily or at all to other more complex domains. More generally, one might subscribe to the dictum suggested by Hoeksema (1985, p14) to the effect that "rule ordering leads to rule paradoxes".

To put a slightly more formal interpretation on this discussion, we may identify two distinct subcases, according to whether the order of application is significant. If we have two transformational rules f and g which may apply in either order, then order of application is significant just in case $f(g(x))$ is different to $g(f(x))$. If this situation does not occur, we may speak of the rules in question "commuting". The atransformational proposal can then be seen as a requirement that all rules in the lexicon commute. Note that this is a stronger condition than the requirement that rules are unordered—any ordering of rules in an atransformational lexicon will produce identical results on some input. This need not hold where rules are unordered but transformational. This topic is taken up again in Section 3.3.4.

2.1.2 Paradigms in linguistic theory

Treatments of WP

In his classic article of 1954, Hockett examined the choices of descriptive framework available to morphologists working in the American structuralist tradition. The focus of debate at the time was whether statements about morphology should be phrased in terms of a set of invariant morphological forms, and their distribution or as a set of processes which convert one form into another. The first of these, *Item and Arrangement* (IA), was the preferred mode of working within this school. The alternative, *Item and Process* (IP), suffered from the stigma of historicity—if a rule converts one form into another, it was argued, the rule has to be interpreted as a recapitulation of historical development and this is inappropriate in a synchronic description. Despite this methodological concern, process descriptions are often to be found within this school (Swadesh and Vogelin (1939) being one of the more famous). Hockett (1954) recognizes that a third mode of description, *Word and Paradigm* (WP), represents an alternative, and probably historically prior, tradition to IA and IP.

As Matthews (1972, p107 fn1) points out, the term 'paradigm' ($\pi\alpha\rho\alpha\delta\varepsilon\acute{\iota}\gamma\mu\alpha\tau\alpha$) which gave rise to the notion of WP morphology is not used in its traditional sense in later work in this framework, such as Robins (1959) and Matthews (1965a,b). I take the traditional sense of paradigm to indicate a system whereby a (possibly abstract) lexical item, described both (typically) orthographically and morphosyntactically, is related to a matrix of nonabstract orthographic forms, the cells in this matrix being associated with particular morphosyntactic properties or operations. This association may be explicitly marked with each occurrence of a paradigm or stated once as a convention for interpreting a set of paradigms. Numerous

Tense	Mood	SINGULAR			PLURAL		
		1	2	3	1	2	3
Present	Indic.	sum	ĕs	est	sŭmŭs	estĭs	sunt
	Subj.	sim	sĭs	sĭt	sīmŭs	sītĭs	sint
S. Fut	Indic.	ĕro	ĕris	ĕrit	erĭmŭs	erĭtĭs	erunt
Imperfect	Indic.	ĕram	erās	erăt	erāmŭs	erātĭs	erant
	Subj.	essem	essēs	essĕt	essēmŭs	essētĭs	essent
		fŏrem	forēs	forĕt	forēmŭs	forētĭs	forent
Perfect	Indic.	fuī	fuistī	fuĭt	fuĭmŭs	fuistĭs	fuērunt *or* ērĕ
	Subj.	fuĕrim	fuerĭs	fuerĭt	fuerĭmŭs	fuerĭtĭs	fuerint
Fut. Perf.	Indic.	fuĕrō	fuerĭs	fuerĭt	fuerĭmŭs	fuerĭtĭs	fuerint
Pluperf.	Indic.	fuĕram	fuerās	fuerăt	fuerāmŭs	fuerātĭs	fuerant
	Subj.	fuissem	fuissēs	fuissĕt	fuissēmŭs	fuissētĭs	fuissent

Figure 2–1: The Paradigm of *sum*, adapted from Kennedy (1918, p168)

examples of traditional paradigms are to be found in Latin and Greek teaching grammars and in reference and descriptive grammars of many modern languages, for example *Le Nouveau Bescherelle* (Hatier 1966). A typical paradigm is shown in Figure 2–1, which gives the forms of the Latin verb *sum*, the copula and auxiliary verb "to be".

A proposal to use such a form of representation in the description of the morphological behaviour of a language contains the implicit prediction that the forms presented by a particular item is suppletive everywhere—there is no means by which we can express a generalization such as "the same operation is used to construct the present form of all verbs with a particular stem".

Such exemplary paradigms, to follow Matthews' (1972, p21) terminology, may be criticized primarily on the grounds of verbosity, but also of inexplicitness, as exemplary paradigms require a set of interpreting conventions which are typically not given. On the other hand, certain features of a paradigmatic presentation are attractive. In particular, one is not committed to those aspects of morphological theory which lead to difficulties in American structuralist approaches. The clearest example of this is fusion; that is, where a form which expresses several different morphosyntactic features is not analyzable into constituent parts which represent those different features. For example, in Latin *puellā* "girl" represents the ablative singular of the word whose nominative singular is *puella* and whose ablative plural is *puellīs* (Lyons 1968, p189). It is impossible in such a case to identify some subpart of these forms which corresponds to the contribution of the feature ablative.

Work by Matthews (1965a,b, 1972) is the most explicit in this area and so it is to a discussion of this that I turn next, in order to have a substantive point of reference to compare with the system I shall present below. All references in this section are to Matthews (1965b) unless otherwise stated. In this presentation, I have made some minor definitional changes, but retained the greater part of his notation.

I have made some notational simplifications, which I trust, are faithful to the spirit of Matthew's work. Latin is the exemplifying language.

A *word and paradigm grammar* is a nontuple G $= \langle L, \Phi, Q, C, W, *\mathrm{T}, *\mathrm{F}, *\mathrm{P}, *\mathrm{R}\rangle$ which, taking $l \in L, q \in Q, c \in C$ and $w \in W$, obeys conditions (4) and (5):

(4) a L is a set of lexemes, $\{\text{CAVEO}, \text{CANIS}, \ldots\}$.

b Φ is a set of orthographic elements, i.e. {a, b, c ...}. Let Σ be the monoid over Φ.

c Q is a set of morphosyntactic properties {imperfect, accusative, singular, active ...}.

d C is a set of morphosyntactic categories $\{\text{MOOD}, \text{CASE}, \text{NUMBER} \ldots\}$.

(5) a $^*\mathrm{T}$ is function from Q to C such that
$^*\mathrm{T}(q) = c \rightarrow \exists q'((q' \neq q) \wedge {}^*\mathrm{T}(q') = c)$.
Let $\textsc{exponents}(c) = \{q | {}^*\mathrm{T}(q) = c\}$.

b A set $K \subseteq Q$ of morphosyntactic properties is *consistent* iff the following holds:
$\neg\exists c, q, q'({}^*\mathrm{T}(q) = c \wedge {}^*\mathrm{T}(q') = c \wedge q \in K \wedge q' \in K)$.
I will write consistent(K).

c Let $\mathcal{K}$ be the set of consistent subsets of Q, i.e. $\mathcal{K} = \{K | K \subseteq Q \text{ and consistent}(K)\}$.

d W is a subset of $L \times \mathcal{K}$ termed *grammatical words*, written $\textsc{canis}_{\textsf{accusative, singular}}$, $\textsc{caveo}_{\textsf{imperative, present, singular}}$, ...

e $^*\mathrm{F}$ is the first projection in W, i.e. $^*\mathrm{F}(\langle l, \mathrm{K}\rangle) = l$.

f $^*\mathrm{P}$ is a relation, a subset of $W \times Q$, such that
$w{}^*\mathrm{P}q \rightarrow w = \langle l, K\rangle \wedge q \in K$.

g $^*\mathrm{R}$ is a relation over Σ and W.

Before continuing, some comments on the above formulation may be of help. The interpretation of $^*\mathrm{T}$ in (5a) is that q is *a term in* or *an exponent of* c. As $^*\mathrm{T}$ is a function, any property is an exponent of one and only one morphosyntactic category. The second part of the definition requires that every morphosyntactic category has more than one exponent. As Matthews notes, the sense of category used here is that of a group of properties which represent some morphological or syntactic classification, where for example singular and plural represent the classification by NUMBER. Thus

(6) a $^*\mathrm{T}(\textsf{imperative}) = \textsc{mood}$

b $^*\mathrm{T}(\textsf{accusative}) = \textsc{case}$.

I will say that singular and plural form a possibly non-binary opposition (in the category NUMBER). (5b) states that a property from a particular morphosyntactic category is inconsistent with any other property from that category. In (5e), $^*\mathrm{F}(w) = l$ is taken to mean *w is a form of l*. For example,

(7) a $^*\mathrm{F}(\textsc{canis}_{\textsf{accusative, singular}}) = \textsc{canis}$

b $^*\mathrm{F}(\textsc{caveo}_{\textsf{imperative, present, singular}}) = \textsc{caveo}$.

The interpretation of w $^*\mathrm{P}$ q in (5f) is that the grammatical word w *has q as a property*. Consequently,

(8) CANIS$_{\text{accusative, singular}}$ *P accusative.

*R is the *realization* relation. That is, σ *R w means that a sequence of characters σ realizes the word w. For example:

(9) c+a+n+e+m *R CANIS$_{\text{accusative, singular}}$.

Using the above definitions, we may go on to define the notion of the *paradigm* associated with a particular lexeme.

(10) The *paradigm* of a lexeme l is the set $\{s|\exists w(s \text{ *R } w \wedge \text{*F}(w) = l)\}$.

To parallel Matthews, we now need to define an ordering over sets of grammatical properties, in particular consistent sets. We induce such an ordering, whose actual content is of little interest here, by first assuming a total ordering over categories and then constraining a total ordering over properties so as to reflect the first order. These orderings over C and Q are then used to induce an ordering over subsets of $\mathcal{K}$. Consider two elements from Q, p and p' such that p' precedes p in the ordering over Q. We may now apply the condition: any set K containing p may only appear earlier in the ordering over $\mathcal{K}$ than K' containing p' if K contains an element q ordered earlier in Q than q' from K', q and q' belong to the same category and that category is ordered before the category to which p' belongs. Allowing, in addition for the case in where a subset relation holds between such sets results in the following definition.

(11) Let $<_C$ be a total ordering over C. Let $<_Q$ be a total ordering over Q, such that $\text{*T}(q) = c \wedge \text{*T}(q') = c' \wedge c <_C c' \rightarrow q <_Q q'$. Figure 2–2 is an illustration of the ordering induced by this first step.
Let $<_\mathcal{K}$ be any total ordering over $\mathcal{K}$, which respects the following conditions:
$\forall K, K' \in \mathcal{K}, (K \subset K' \rightarrow K <_\mathcal{K} K')$.
$\forall K, K' \in \mathcal{K}, \exists p \in K, p' \in K'(p >_Q p' \wedge K <_\mathcal{K} K' \rightarrow \exists q \in K, q' \in K'(q <_Q q' \wedge \text{*T}(q) = \text{*T}(q') \wedge \text{*T}(q) <_C \text{*T}(p')))$

An alternative way of viewing this definition is as a sorting function which sorts first on the basis of category membership and secondly on the basis of the ordering defined over Q.

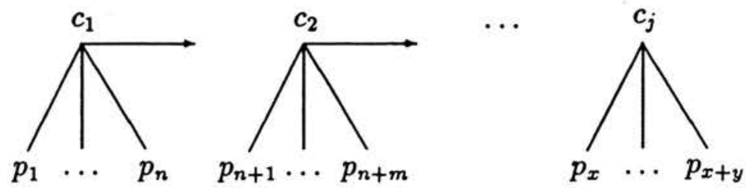

Figure 2–2: A total ordering over morphosyntactic properties and categories.

The *arrangement* of a paradigm corresponds to some ordered representation of a paradigm. Figure 2–2 gives a graphical representation of the ordering over morphosyntactic properties and categories defined in (11).

(12) An *arrangement* of a paradigm of a lexeme l is the totally ordered set $\langle \mathcal{K}', < \rangle$ of pairs, $\mathcal{K}' \subseteq \mathcal{K}$, where
$\langle \mathcal{K}', < \rangle = \{\langle K, s\rangle | \langle l, K\rangle \in W \wedge s \ {}^*\mathrm{R} \ \langle l, K\rangle\}$
where $K_1 \in \mathcal{K}', K_2 \in \mathcal{K}', K_1 < K_2, p_1 \in K_1, p_2 \in K_2, p_2 <_Q p_1 \rightarrow \exists q_1 \in K_1, q_2 \in K_2({}^*\mathrm{T}(q_1) <_C {}^*\mathrm{T}(q_2))$

That is, the ordering over K must respect the ordering first of morphosyntactic categories, then of the properties that are exponents of those categories.

Matthews (1965a, 1972 Ch. 9) defines the "inflectional component of a Word and Paradigm" grammar, or, to be more specific, that part of a WP grammar responsible for determining the realization relation *R discussed above (9). This takes the form of a series of transformations over graphemic (or phonological) representations. These transformations are expressed in rules of the following form:

(13) *Reference:* $\left\{ \begin{array}{l} \text{Verb} \\ \textsf{perfect, present indicative, first, singular} \end{array} \right.$
Operand: Primary Stem
Operation: Suffix ī

Matthews (1972, p173) glosses this rule as (with notational changes on my part):

(14) A Verb-form is derived from its Primary Stem by the Suffixation of ī provided that the word which it realizes has all the properties perfect, present indicative, first, singular.

The term *Primary Stem* is used to refer to the intermediate form in a derivation which is derived from the root form, possibly by infixing operations (Matthews 1972, pp172ff). The rule therefore allows the derivation of a form such as *scandī* from *scand*, given that SCANDO$_{\text{perfect, present indicative, first, singular}}$, "climb", has the latter form as its Primary Stem. More generally, the *reference* component of a rule states the properties of a word which are required to allow the realization of a form by the specified operation. Equivalently, it describes a position in a paradigm, and we may see the rule in question as working from the basic representation of some lexeme "towards" its realization at that point in the paradigm. The *operand* states the form of the input to the rule and the *operation* describes the graphemic effect of the rule. Matthews allows two extensions to the basic rule format described above. The first is illustrated here:

(15) *Reference:* $\left\{ \begin{array}{l} \text{Primary Stem} \\ \text{perfect} \end{array} \right.$
Limitation: L
Operand: Root
Operation: Vowel-lengthening

The *limitation* states that a rule is only applicable to some subset of those words picked out by the reference component. In this case, L is taken to include the lexemes RUMPO "break", CAVEO, "take heed", and so the rule will allow the derivation of the Primary Stem *rūp* from the Root *rup*. A rule may not apply if there is another whose limitation is more specific (see Section 2.4.1 below for further discussion of this point).

The second extension is to allow for derivations of the Priscianic or parasitic kind (Matthews 1972, p169, see also Section 3.3.2 of this thesis), that is, where a form is derived from some other derived form. In this case, Matthews allows the further specification of the operand of a rule to indicate the form from which derivation is to proceed. So to allow for the derivation of the future participle from the past participle, he proposes the rule:

(16) *Reference:* $\left\{\begin{array}{l}\text{Primary Stem}\\ \textbf{future participle}\end{array}\right.$
Operand: $\left\{\begin{array}{l}\text{Primary Stem}\\ \textbf{past participle}\end{array}\right.$
Operation: Suffix ūr

which mentions the morphosyntactic property **past participle** in the operand, to state that this property is required to hold of the input to the rule, but that it may possibly not hold of the form that is derived using this rule. A rule may therefore effect a transformation over morphosyntactic and graphemic representations. In this case, the rule will allow the derivation of the Primary Stem *rectūr* from the Primary Stem *rect*, on the basis of the lexeme REGO, "keep right" and its root *reg*.

Matthews (1972, p171) indicates that derivations in such a system may be described as transitions through a finite state machine, whose states are defined by the terms "Verb" (or more generally any "Form-class"), "Primary Stem" and "Root". In the first case above, the transition will be from "Primary Stem" to "Verb", in the last from "Primary Stem" to "Primary Stem". It is essentially this information that is used to drive the process of derivation.[1]

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[1]We may note that, in two respects, Matthews is less explicit than one might expect, given the standard of the rest of his work. His use of the term *root*, while justified informally, is not cashed out in the formal system he proposes. Matthews implies (p64 and p182) that the root of a lexeme such as MONEO can be viewed as the sequence of graphemic elements *mon*. However, there is no explicit relation in Matthews' system stated to hold between lexemes and roots, but such a relation is required (cf. step 8 in Matthews' flow chart p178, and p181) and is not derivable from any of the other relations he states. This lack is however easily repaired by stating a function "has the root form" from L, the set of lexemes, to Σ the set of strings drawn from Φ.

Another omission is the formal definition of the objects that correspond to the terms "Verb", "Primary Stem" and "Root". That is, the terms that define the finite-state machine and the set of cover terms for possible intermediate derivations do not figure in the formal definition of a WP grammar.

This process then consists of constructing, on the basis of possible transitions through the finite-state machine, an intermediate representation which is essentially a word annotated with an indication of the graphemic operations to be applied. The realization of a word is then computed by applying the graphemic operations in the order that follows that of the transitions.

To sum up, Matthews' system is intended primarily to take advantage of the paradigmatic mode of description, while avoiding the the disadvantages mentioned at the beginning of this section.

The framework of WP morphology is taken up again in Anderson (1982) and in the papers in Thomas-Flinders (1981a), under the rubric of *Extended Word and Paradigm* (EWP) Morphology. The main technical innovations in these works are to frame all rules in terms of pairs of phonological and morphosyntactic specifications and to allow morphosyntactic specifications to be recursive. In addition, the use of "lexeme", as a defined term in the theory, seems to be omitted within EWP. That is, the objects in a morphological description are pairs of phonological (or orthographic) and morphosyntactic specifications (Anderson 1982, 1988a, p179):

(17) {S, M}

Morpholexical rules, similar to those proposed by Matthews, also figure in the formalism. However, the terms which Matthews uses to define his finite-state machine, are absent in EWP, which leads to a general question about how the process of derivation is constrained in such a formalism.

The proposals in Chapter 3 of this thesis can be seen as an attempt to supply a framework which is closer to the traditional notion of paradigmatic morphology, in that paradigms are explicitly represented. That is, paradigms will appear as objects in a linguistic description rather than being derivable in some way or other from other statements. Such an endeavour is worthwhile as the existence of paradigms in some form or other is often presupposed, often with little indication of the formal status of paradigms or how they are determined. Two examples taken more or less at random from the literature are Halle (1973) and Jaeggli and Safir (1989). In the second, the property of *morphological uniformity*, that is where a language either presents unique forms at every position in a paradigm or shows no variation at all across positions, is suggested as a way of picking out those languages which demonstrate the phenomenon of PRO-drop (Chomsky 1981, *inter alia*).

2.2 Morphology in computational linguistics

In this section we review work on morphology in the field of computational linguistics. In making the distinction between linguistics and computational linguistics, I do not wish to suggest that the aims and methodologies of the two disciplines are irreconcilable. Rather, work in these two fields to date has tended to have somewhat different immediate concerns, alluded to in 1.2. This tendency has been particularly marked in the area of lexical representation. For the computational linguist, the aim in constructing a lexicon has often been to describe a small set of lexical items in a concise, computationally effective way which are then used in conjunction with some syntactic processor. The aim is to test the theory of syntax or the processor, rather than to develop a theory of lexical representation. The comments by Shieber in Whitelock *et al* (1987, p234) support this view. More recently, the study of larger lexicons has been given impetus from the availability of machine-readable dictionaries. Within the theoretical study of lexical representation, the application of techniques from computer science for the representation and manipulation of data bases has been fruitful.

2.2.1 Finite State Morphology

Koskenniemi (1983) presents a system for the description of morphographemic alternations whose basic mechanism is the *finite state transducer* (FST). A standard finite state machine consists of states, transitions between states labelled with characters and an indication of the possible start and end states. A finite state transducer is similar to standard finite state machines, except that transitions between states are labelled with pairs of characters, one of which represents the "surface" character, the other the "lexical" character. A transducer therefore represents a relation between strings of surface and lexical characters. The standard interpretation of such a model is to assume the existence of a lexical and a surface "tape", on which are written strings of characters. A transducer *accepts* a pair of tapes if, starting from a possible start state, transitions can be made through the transducer which match characters on the appropriate tape with those labelling the transitions, ultimately arriving at a possible end state. Typically, more than one transducer will be in use, in which case a pair of tapes is accepted if it is accepted by all transducers.

Analysis of some morphological phenomenon is therefore made in terms of statements about possible lexical-surface correspondences, hence the alternative name *two-level morphology*. The alphabets defining possible lexical and surface characters may be different. For example, Karttunen and Wittenburg (1983) present a treatment of English in which the symbol ‘'’ may appear on the lexical tape to mark the position of a stressed syllable, thereby conditioning a range of morphographemic effects. The surface alphabet, on the other hand, does not contain this character.

Two-level morphological analyses exist for a wide range of languages (for references, see Gazdar and Mellish 1989, p62). Perhaps the major attraction of finite state morphology (FSM) is computational. Finite state machines represent the simplest and most tractable form of computational machine. The languages they define are closed under standard operations such as intersection and union (although it is not clear that this property also holds for finite state *transducers* in general). The computational use and manipulation of such machinery is well understood and, the comments of Barton *et al* (1987) notwithstanding, typically efficient. As my proposals below represent a considerable step away from a finite state treatment of morphology, I present two arguments as to why a finite state approach may be undesirable. The first of these is based on the inability of the finite state approach to characterize certain phenomena in a perspicuous way, the second on the relation of statements about morphological behaviour to the rest of the grammar.

The first argument may be stated thus: a proper account of morphosyntactically conditioned alternation requires either *ad hoc* analysis or a possibly non-finite state extension of the mechanism. Jones in Calder *et al* (1989, p29) gives examples of the varying behaviour of elision in German according to the morphosyntactic properties of the item in question. In this case, verbs and adjectives exhibit different behaviour under the suffixation of "en". In the case of verbs, "en" marks the infinitive form. In the case of adjectives, it represents an inflection for a variety of possibilities of number case and gender.

(18) a verdunkel, verdunkeln "darken"
 b dunkel, dunklen "dark"

To describe this pair of examples within the framework of finite state morphology requires the conditionalization of the rules that describe elision to be sensitive to the morphosyntactic class of the item being analyzed. One may do this in one of two ways. One may either set up two distinct lexical characters, one of which will appear prior to the final liquid in the representation of verbs, the other under the same condition in that of adjectives. These different characters will condition different forms of elision. Alternatively, one may extend the notion of transition for an FST to include morphosyntactic information. The difficulty with the second course is that some regime for integrating this information with that presupposed by FSM must be developed. This course may jeopardize the finite state nature of the system. This said, work by Carson (1988) represents an initial step towards the integration of feature-value specifications with finite state transducers for the treatment of phonological features.

Neither of these solutions is particularly attractive from a theoretical point of view—they both require the conflation of information from the orthographic (or phonological) domain with that from the morphosyntactic domain. More generally, examples of circumfixation in Finnish, described by Karttunen (1983, p180), may lead to the duplication of information about material appearing inside the circumfix. Further examples might be taken from compounding in the language Bambara (Culy 1985, Gazdar 1985a) to indicate the inadequacy of finite state methods in general. However, as Anderson (1988a, pp149, 187) notes, compounding is held to be the most syntactic of morphological processes, and so this evidence is perhaps more marginal.

The second of my arguments is that a finite state approach to morphological description sits uneasily with the logical approach to grammatical description to be described in the next section. While not denying the computational virtues of FSM, concerns of computational efficiency should not be the overriding factor in determining the design of a formalism for linguistic description. If we wish to view our statements as *descriptions* of linguistic objects, it is arguably a confusion of levels to constrain our statements on computational grounds. It is certainly an interesting fact about natural languages that the majority of morphological phenomena appear to be explicable in finite-state terms, and we may make use of this fact in computational interpretations of grammatical formalisms. However, if we introduce finite-state transducers to describe the relation between different forms of the same item, our descriptions are in a sense *indirect*—we have to interpret the operations of the tranducers in order to determine the forms that are related.

The proposals I make in Chapter 3 offer a more direct connection between our descriptions of orthography and those about the morphosyntactic behaviour of items. This is achieved by representing orthographic information in essentially the same way as other types of information. I now turn, therefore, to a review of the logical basis of frameworks which will allow this form of representation.

2.3 Logical approaches to linguistic description

One of the major changes in approaches to linguistic description witnessed in the 1980's was the emergence of comprehensive formal treatments of the apparatus of grammars, in particular in terms of logics which allow the description of systems of features and values. I will not recapitulate the history of these developments which are documented in sources such as Kay (1985), Johnson (1987, Ch. 1) and Wedekind *et al* (1990). In this section, I will concentrate specifically on the notion of *subsumption* and on the algebraic treatment of feature value logics and review work under the heading of *Universal Unification*, with particular reference to the treatment of structures such as sequences. The logical properties of feature structures will inform the development in Chapter 3 of a system for morphosyntactic description, while the linear organization of sequences will underpin my treatment of orthographic information.

2.3.1 Unification and Subsumption

It is a *sine qua non* of formalisms described above, for which I will use the cover term *unification-based*, that they make use of a fundamental operation which is

- information-combining and
- procedurally neutral.

Taking these in turn, *information-combining* means that the operation in question can be modelled logically as the conjunction of descriptions, as in Pollard and Sag (1987, Section 2.1), or by the conjunction of equalities (Johnson 1987, Shieber *et al* 1983). In other words, to assert that two feature structures, viewed as (or described by) formulas in an appropriate logic, are combined or unified is to assert the logical conjunction of the formulas. This simple picture may be complicated by the existence of some "background axioms" or theory with which all feature structures must be consistent, and so we might replace the last part of our sentence above by "assert the logical conjunction of the formulas and all consequences thereof". A standard assumption in feature-value logics is that the "appropriate" logic is *monotonic*, that is the set of theorems derivable from some set Σ of statements is a superset of those derivable from some other set Σ' if $\Sigma \supseteq \Sigma'$.

Procedural operations make reference to some aspect of the current state of computation to the extent that the effect of an operation can only be explicated in terms of a mapping between computational states. Examples of such operations are the destructive assignment of a value to a variable or the explicit scheduling of actions. Conversely, *procedurally neutral* or *declarative* describes an operation or operations with an interpretation in terms other than as a computational procedure. Such an operation might be understood as some kind of statement in a logic and the interpretation of that logic will provide an interpretation for the operation in question. (This, of course, does not preclude a computational interpretation in addition to the logical interpretation.) In some cases, the irrelevance of the order of operations may be evident from axioms that hold in the logic. This may be seen in the statement of the commutativity of conjunction (C for commutativity—I will follow the practice of Siekmann (1989) *inter alia* of referring to axioms by their initial). Pollard and Sag (1987, p38) define the following to be true of all feature structures:

(19) C: $\mathrm{A} \wedge \mathrm{B} = \mathrm{B} \wedge \mathrm{A}$

This axiom, together with the axiom of associativity (A),

(20) A: $(\mathrm{A} \wedge \mathrm{B}) \wedge \mathrm{C} = \mathrm{A} \wedge (\mathrm{B} \wedge \mathrm{C})$

implies that we may combine feature structures in any order whatsoever without affecting the result.

Conjunction in this setting is simply the accumulation of information. That is, A $\wedge$ B typically represents more information than either of the feature structures A or B alone. The notion of ***subsumption*** allows us to compare feature structures as to their informativeness. Pollard and Sag (1987, p38) give the following definition of subsumption.

(21) A ***subsumes*** B (A $\geq$ B) iff A $\wedge$ B = B

That is, a feature structure B is more informative than another A if their conjunction is exactly as informative as B. We may therefore refer to A as more general (or less specific), and B as less general (or more specific). Notation varies widely in discussions of subsumption in the literature. In this thesis, I will use the symbol '$\geq$' to indicate subsumption and write A $\geq$ B for A the more general and B the more specific. I will also use B $\leq$ A with equivalent meaning. The notion of subsumption is closely related to that of logical consequence. If one feature structure subsumes another, the more general is a consequence of the more specific.

2.3.2 The Algebraic Treatment of Feature Structures

The axioms above, together with (22) Idempotence (I), Top (T), Bottom (B) and appropriate definitions for disjunction (23) (Pollard and Sag 1987, p42),

(22) I: $A \wedge A = A$
T: $A \wedge \top = A$
B: $A \wedge \bot = \bot$

(23) A: $A \vee (B \vee C) = (A \vee B) \vee C$
C: $A \vee B = B \vee A$
I: $A \vee A = A$
T: $A \vee \top = \top$
B: $A \vee \bot = A$

(24) $A \geq B \leftrightarrow A \vee B = A$

provide a basic system for the description of feature structures, including the privileged elements $\top$, the uninformative feature structure, and $\bot$, the inconsistent feature structure. As this formalism contains both conjunction and disjunction, the axioms of distributivity indicate how these operations are related:

(25) D: $A \vee (B \wedge C) = (A \vee B) \wedge (A \vee C)$
D: $A \wedge (B \vee C) = (A \wedge B) \vee (A \wedge C)$

Pollard and Sag further extend this system with the addition of a negation operation '$\neg$' with the definition

(26) $\neg A = (A \Rightarrow \bot)$

with the informal gloss that $\neg A$ is the most general feature structure such that its conjunction with A yields the inconsistent element $\bot$. Here '$\Rightarrow$' is the *relative pseudocomplement* operator of a Heyting Algebra (Burris and Sankappanavar 1981, p17, Grätzer 1971, pp165ff, Curry 1977, pp140ff, Goldblatt 1979, pp178-186). Perhaps the most illuminating definition of this operator is that given by Goldblatt (1979, p181):

(27) $A \Rightarrow B = \bigvee\{C \mid C \wedge A \leq B\}$

That is, the relative pseudocomplement of a feature structure B with respect to another A is the disjunction of all feature structures C such that the conjunction of A and C is at least as specific as B. The use of disjunction in this definition enforces the condition of maximum generality; if there are two feature structures C_i, C_j in the set generated by

(28) $\{C \mid C \wedge A \leq B\}$

and $C_i \geq C_j$, then by (24), $C_i \vee C_j = C_i$, and so C_j will not appear as a disjunct in $A \Rightarrow B$.

With the above formalization, we may define equivalence as mutual subsumption, i.e.

(29) $A = B \leftrightarrow A \geq B$ and $B \geq A$

and strict subsumption as subsumption prohibiting equivalence, i.e.

(30) $A > B \leftrightarrow A \geq B$ and $A \neq B$

In addition to its use in defining negation, the operation of relative pseudocomplementation is used to state implicational relations holding between feature structures. Thus, Pollard and Sag (1987, p48) give the following statement of the relation between the complements of the head of an expression and those of the mother of an expression:

(31) $$\mathit{phrasal\_sign}[\,] \Rightarrow \begin{bmatrix} \text{SYN}|\text{LOC}|\text{SUBCAT} & \boxed{1} \\ \text{DTRS} & \begin{bmatrix} \text{HEAD-DTR}|\text{SYN}|\text{LOC}|\text{SUBCAT} & \text{append}(\boxed{1}, \boxed{2}) \\ \text{COMP-DTRS} & \boxed{2} \end{bmatrix} \end{bmatrix}$$

This says that, if a feature structure represents a *phrasal sign*, then the sequence of elements that represents the subcategorization of the head daughter is the concatenation of the sequence of elements which is the value of the feature COMP-DTRS with the sequence that represents the phrasal sign's subcategorization.

Most of the theorems used by Pollard and Sag represent well-accepted logical equivalences. However, the type of implication that relative pseudocomplementation defines is *intuitionistic* rather than *classical.* In classical logic, the following is required to hold of negation:

(32) $\neg\neg \mathrm{A} = \mathrm{A}$

whereas intuitionistic negation has the following, weaker condition:

(33) $\neg\neg \mathrm{A} \geq \mathrm{A}$

In other words, under the intuitionistic construal of negation, the double negation of a feature structure A is possibly more general than A.

Pollard and Sag (1987) give no motivation for their choice of an intuitionistic rather than a classical logic. One possible factor is the demonstration by Moshier and Rounds (1987) that classical negation may be construed as nonmonotonic (Mike Reape, personal communication). However, work by Johnson (1987) and more recently Dawar and Vijay-Shankar (1989) suggests that there are treatments of classical negation which preserve monotonicity.

It is furthermore simple to reconstrue statements in a Heyting algebra as statements in a classical framework by adding the further condition:

(34) $A \Rightarrow B = \neg A \vee B$

and the resulting algebra is a Boolean algebra (Burris and Sankappanavar 1981, p27). Boolean algebras give a classical interpretation of negation.

It seems at the moment that there is little linguistic evidence to favour either a classical or an intuitionistic interpretation of implication and negation. In what follows, I will not take a stand on this issue.

I will present one further technical concept related to that of subsumption. If we know that two feature structures stand in a subsumption relation, $A \geq B$, then we shall want to talk about the set of feature structures that "lie between" A and B. The technical term is *interval*, of which there are two kinds. A *closed interval* [B,A] includes its endpoints, A and B, and receives the definition:

(35) $[B,A] = \{C \mid B \leq C \leq A\}$

The *open interval* (B,A) between two feature structures does not include the endpoints, and is then:

(36) $(B,A) = \{C \mid B < C < A\}$

I will make use of intervals in several definitions to be seen below.

To sum up, the algebraic treatment of feature structures allows a simple description of the behaviour of feature structures under a variety of operations and results obtained within the study of algebras may be exploited within a linguistic context. Furthermore, as algebra is, in essence, the study of the similarities of structures, we may view that statements we make within an algebraically defined theory as relatively abstract; any set of objects which respect the algebraic structure we define will have the behaviour we require.

Two further points should be made in this connection. First abstractness means that questions of the actual system we choose to construct our descriptions in are of less importance than the *behaviour* of that system. In Chapter 3 below, I present a propositional system. That is, rather than defining objects as formulas in a feature value logic (and so effectively using a first order, quantifier free logic, Johnson 1987), I make use of a propositional logic—statements are constructed from propositional constants and the operations of conjunction, negation, *et cetera*. The difference between these systems is for our purposes unimportant, as it is simple to show that any propositional system can be embedded within the more powerful feature value logic. Importantly, the discussion of subsumption above carries over completely into this new context.

The second point is that, in using some formula ϕ as a description, we are in effect referring to a whole class of formulas. Technically, we are dealing with the quotient algebra generated by the equivalence relation defined by logical equivalence. (Burris and Sankappanavar 1981 p35, Davey and Priestley 1990, p119). Informally, we may consider the set of all descriptions to be ordered by logical consequence. The order that so results is a preorder. Logical equivalence then partitions this set into equivalence classes and the preordering over descriptions induces a partial ordering over these equivalence classes. A formula is then a kind of shorthand for an arbitrary member of one of these equivalence classes. This perspective allows us to abstract away from details, such as the names of variables or the order in which conjuncts are stated. This perspective mirrors the distinction made by Kasper and Rounds (1986) and Johnson (1987) between description and object, that is between the expression written down in the theory and the object or objects that may satisfy such expressions.

In practice, it is often convenient to ignore the distinction between a description and the corresponding equivalence class. Indeed, there is only one case below in which I shall advert to it, namely in the description of derivability, in section 3.1.1, page 82.

2.3.3 Extensions to unification-based formalisms

The system defined above, while powerful, may fail to be adequate for a perspicuous and general treatment of linguistic phenomena. Accordingly more complex mathematical structures have been proposed, for example in the treatment of adjuncts. Thus, Pollard and Sag (1987, p161) propose to represent the adjuncts that may occur with some expression in terms of a set of elements (see also Kaplan and Bresnan 1982) and use list-valued features (or *sequence* descriptions) to describe the complementation pattern of expressions (Ch. 5, cf. also (31) above). Sanfilippo (1990) presents further applications for sequence descriptions. Wedekind *et al* (1990) present a survey of other proposed extensions.

As the types of structures presupposed by unification-based formalisms increase, a question which arises is whether there is a general framework within which to couch such extensions. The field of Unification Theory (Siekmann 1984, 1989) attempts to answer this question. To paraphrase Siekmann (1989, p207ff), in a wide range of disciplines, of which linguistics (or computational linguistics at least) is one, the central problem is the "matching of descriptions"—that is, are two descriptions compatible and, if so, what is the description that results from taking their combination? Furthermore, we may have a *theory* of descriptions, which gives an interpretation of the symbols from which we construct our descriptions. In this case, what are the formal and computational consequences for the unification problem according to our choice of theory? Siekmann offers the following "most abstract" formulation of the problem:

> Let $\mathcal{L}$ be a formal language with variables and two words s and t in that language. Then for a given binary relation $\approx$ defined in $\mathcal{L}$ find a substitution σ such that $\sigma s \approx \sigma t$ (provided of course that σs and σt are well defined). [1989, p209]

In the case of Pollard and Sag's (1987) formalism, mutual subsumption plays the role of $\approx$ and $\mathcal{L}$ is defined as the set of well-formed formulas induced by the axioms discussed in (19), (20) and (22) and the feature value notation.

The key notion in unification theory is that of *most general unifier*. Put simply, a unifier is any substitution that makes the descriptions to be unified identical. The following example, taken from Siekmann (1989, p207) and where it is assumed that the empty theory, i.e. the theory with no axioms, is in force, gives two terms to be unified s and t, and a resulting unifier δ, where x/u indicates that the term u is to be substituted for the variable x:

(37) $s = \mathrm{f}(x, \mathrm{g}(\mathrm{a}, \mathrm{b}))$
$t = \mathrm{f}(\mathrm{g}(y, \mathrm{b}), x)$
$\delta = \{x/\mathrm{g}(\mathrm{a}, \mathrm{b}), y/\mathrm{a}\}$

However, if we assume that the symbol f is commutative, that is

(38) C: $\mathrm{f}(x, y) = \mathrm{f}(y, x)$

then δ is no longer the only unifier. There is another $\sigma = \{y/\mathrm{a}\}$ because the following holds:

(39) $\sigma s = \mathrm{f}(x\ \mathrm{g}(\mathrm{a}\ \mathrm{b})) =_C \mathrm{f}(\mathrm{g}(\mathrm{a}\ \mathrm{b})\ x) = \sigma t$

where $=_C$ means that two terms are equivalent under the axiom C. σ is *more general* than δ—any term described by δt is also described by σt (for a more satisfactory formal definition, see Siekmann 1989, Section 2.2). In this case, σ is a *most general unifier* (mgu). It is more general than δ—if δ is a possible substitution, σ also is—and there is no other substitution which makes s and t equal. Siekmann then illustrates cases of theories which result in an infinite set of mgus. We shall see such a case shortly.

Siekmann (1989, p222) presents a digest of results where the unification problem under particular theories is classified according to the types of unifiers that solve equations in that theory. The unification problem for a theory is of type:

(40) a *unitary* if, for every equation in the theory, the set of mgus exists and has at most one element,
b *finitary* if, for every equation in the theory, the set of mgus exists and is finite,
c *infinitary* if, for every equation in the theory, the set of mgus exists but is possibly infinite and
d *nullary* if, for some equation in the theory, no set of mgus exists.

The unification problem is ***decidable*** in some theory if it can be determined that there is at least one unifier for any solvable problem in that theory. Results for a variety of theories are tabulated in Siekmann (1989, p225).

With this summary of the required formal apparatus in place, I now turn to a discussion of descriptions that will be of particular importance in the following chapters of this thesis, namely descriptions of *strings*.

2.3.4 String and Sequence Descriptions

A *string* σ is a finite sequence of elements drawn from the finite set C of characters combined by the associative operator $+$, representing the concatenation of strings. A *string specification* or *string form* is a sequence possibly containing variables drawn from the set V.

The following axioms define the behaviour of strings from an algebraic point of view, where ε represents the empty string:

(41) A: $x + (y + z) = (x + y) + z$

U: $x + \varepsilon = \varepsilon + x = x$

Of these axioms, Associativity states that strings have essentially no structure— any bracketing of a string is possible. Unit states that there is a unit or identity element whose appearance is irrelevant in a description of a string. The formal similarity of axioms U and T in (22) above will be noted.

Omission of the operator $+$ increases legibility, as shown in the right hand column of (42), which gives examples of strings (a,b) and string specifications (c-e). Note that I will never omit the operator + when it separates a variable and a character or two variables. The convention that italic characters represent string variables will be used throughout the remainder of this thesis. Let $C = \{$a, k, l, ö, r, s, t, w$\}$ and $V = \{a,\ c,\ d,\ e,\ v,\ w,\ x,\ y,\ z\}$.

(42)			
	a	w+a+l+k+s	walks
	b	s+ö+r	sör
	c	a	a
	d	w+s	w+s
	e	k+v+t+v+b	k+v+t+v+b

String specifications are ***partial descriptions*** of strings. As with the standard use of unification in computational linguistics (Shieber *et al* 1983, Pereira 1987), two partial descriptions may describe the same object. We may use conjunctions of string descriptions, for which I shall employ the symbol $\wedge_s$, to represent this situation. The examples in (43) show string conjunctions and an assignment of values to variables which satisfy the descriptions. Following common practice, I will refer to the result of applying a unifying substitution to either string in a conjunction as the unification of the two string specifications in question.

(43)		Description	Unifying Substitution
	a	walks $\wedge_s$ w+s	w/walk
	b	sör+a+k $\wedge_s$ $x+y+z+y+w$	a/ö, y/ö, x/s, z/r, w/k
	c	k+v+t+w+b $\wedge_s$ c+i+d+a+e	v/i, w/a, c/k, d/t, e/b

The string unification problem, also known as the ***Monoid problem***, is discussed in various forms by Siekmann (1975, 1984, 1989), Schmidt-Schauß (1986) and Baader (1986). The problem amounts to the determination of "whether or not an equation system over a free semigroup possesses a solution" (Siekmann 1989 p. 8 and references therein). In this form the problem has been shown to be decidable. However, a principal concern of research in formalisms developed for linguistic description is not only to determine that a solution to some problem exists, but also to compute solutions for use in derivations. A solution typically takes the form of an mgu, or of the result of applying a unifier to one of the terms. (As Johnson (1987, p86) describes the latter case: "...we are interested in characterizing the sets of models that satisfy [a set of formulas]"). In the general case of unification under Associativity (A) alone, there may be an infinite number of solutions to some problem and those solutions cannot be finitely represented (Siekmann 1975, section 4.3. See also Siekmann 1989, p208). Following the terminology of (40), A is of type *infinitary*. As a computational consequence, no algorithm for solving unrestricted problems in A can be expected both to be complete, that is to find all solutions to a given problem, and to terminate.

Also of interest in the present context is the combination A+U, where we have a linear structure and some element—the empty string—which is an identity element under concatenation with any string. Siekmann (1989, p235) reports complexity results by Makinin (1977) which show that the unification problem for the combination A+U is decidable, but does not give any indication as to the classification of this particular problem in terms of (40). The examples (b,c) in (43) above show the existence of multiple mgus in the case of A+U unification. In (b), we may also construct a unifying solution

(44) $\{x/\text{sőr}{+}a{+}\text{k}, y/\varepsilon, z/\varepsilon, w/\varepsilon\}$

which is neither more nor less general than the unifier given in the example above. From this we can conclude that A+U unification is of a type greater than unitary. We might conjecture that the problem is unlikely to be of type less than infinitary on the grounds that for any unifier which substitutes an empty string for a variable x there may be a more general unifier which substitutes some other variable for x—the axiom U does not in general reduce the number of unifying substitutions. This thesis is not the place to investigate such questions. It is however worth emphasizing that, as (41) is a natural axiomatization of structures such as strings and sequences, an answer to this question is important for an understanding of the properties of formalisms that use such structures.

The upshot of these results is that no complete, terminating algorithm for the general case of string unification (i.e. under A or A+U) exists and obvious questions result from the proposal for its use within a linguistic formalism. I here appeal to the arguments put forward by Johnson (1987, p123) and Koskenniemi and Church (1988), which may be summarized as follows: *in discussing matters such as computational complexity or decidability, it is the grammars encoded in some formalism that should be evaluated, rather than the inherent properties of the formalism itself.* Many formalisms, such as PATR-II (Shieber *et al* 1983) and Johnson's AVL (Johnson 1987), are undecidable. This property has not diminished the utility of grammars encoded in them. The kinds of linear structures described by strings and sequences seem to arise naturally in linguistic descriptions (see Pollard and Sag (1987, p. 148), Reape (1989), Bird and Klein (1990)). Therefore, it is reasonable to make use of such mathematical devices.

It is of course also important to investigate restrictions that allow such formalisms to be computationally effective. In this connection, the class of problems in A described by Siekmann (1975, section 4.3.3.2) as $P_{0.5}$, where repeated variables are only permitted on one side of conjunction, gives rise to only finitary mgus. It will be observed that Siekmann's formulation of this restriction is potentially ambiguous, in that it has either the interpretation "only a particular side of an equation may contain all variables that occur more than once" or that of "if one side of an equation contains an occurrence of a variable then any other occurrence of that variable must also be found on that side". It is clear from Siekmann's later comments and examples that both of these conditions must be satisfied in order for an equation to fall within $P_{0.5}$.

The following examples fall inside (45) and outside (46) the class:

(45) $x \wedge_s y$
$x \wedge_s y + y$
$x + y \wedge_s w + z$
$x + \mathrm{e} \wedge_s \mathrm{lov} + e$
$x + y + x + z \wedge_s \mathrm{haoharde}$

(46) $x \wedge_s x + \mathrm{a}$
$x \wedge_s x$
$x + y \wedge_s x + y$
$\mathrm{c} + x + c + y + c \wedge_s s + v + t + v + u$

Note that the first case in (46) represents the pathological case in which the only solution is the infinite string consisting only of occurrences of the character "a".

Unless otherwise noted, all subsequent examples of string unification fall within the $P_{0.5}$ class of string unification under the axiom A alone. I shall be careful to point out any case which diverges from this statement, either by falling outside the $P_{0.5}$ class or by necessary use of the axiom U. More comments on this topic are to be found in Section 3.3 below.

A further point that needs to be addressed here is the "result" of the unification operation when mgus are not necessarily unique. In the case of finitary problems, the multiple mgus will give rise to solutions which are distinct, in the sense that no subsumption relations hold between them. Thus, the conjunction of descriptions in (47a) gives rise to the set of unifiers in (47b)

(47) a x+n+y $\wedge_s$ banana
b $\{\{x/\text{bana}, y/\text{a}\}, \{x/\text{ba}, y/\text{ana}\}\}$

If the variables x and y are used elsewhere to construct other string specifications, then the different assignment of values to these variables will imply a variety of different string specifications. In other words, the operation of unification may be a relation rather than a function. In practice, however, all the conjunctions of string specifications used below in the context of grammatical statements give rise only to unitary mgus. This typically results from the fact that the string specifications constrain characters at the extremities, and that, in effect, variables are used to analyze some portion of a string in a context which constrains any other portion of the string to consist of a known number of characters.

For this reason, various definitions, in particular that of the unification of lexical specifications on page 74, build in the assumption that only one most general unifier constructed on the basis of a conjunction of strings exists. Situations in which the set of unifiers generated by the unification of two strings descriptions is not a singleton will be treated in the same manner as those in which no unifiers exist. This assumption does not appear to cause any practical difficulties, but would of course have to be revised if cases were found that require the generation of alternative analyses from the unification of two given string descriptions. Hereafter, then, the following definition of string unification will be in force:

(48) Let σ and τ be string descriptions and let Θ be the set of mgus implied by the conjunction $\sigma \wedge_s \tau$. The unification of σ and τ is then $\theta(\sigma)$ provided that $\Theta = \{\theta\}$.

The relation of ***subsumption*** defines a partial ordering on string specifications. A string specification σ *string subsumes* another σ' ($\sigma \geq_s \sigma'$) iff a unifier θ exists such that $\theta(\sigma) = \sigma'$.

(49)

	More general		Less general
a	w	$\geq_s$	walks
b	w+s	$\geq_s$	wal+s
c	s+o+r+o+k	$\geq_s$	s+ö+r+ö+k

Subsumption provides a precise notion of the information conveyed by a string specification and it will play an important role in the system to be developed in the next chapter. A further notion we will need is that of *strict* subsumption $\sigma >_s \sigma'$, defined in (50):

(50) $\sigma >_s \sigma' \leftrightarrow \sigma \geq_s \sigma'$ and $\sigma \not\approx_s \sigma'$

where $\approx_s$ is the relation of equivalence of strings, defined as follows:

(51) $\sigma \approx_s \sigma'$ iff $\{s|\sigma \geq_s s\} = \{s'|\sigma' \geq_s s'\}$

With this definition of equivalence in place, we may make the same abstraction here as we did in Section 2.3.2. That is, rather than viewing a string specification as a concrete object, we may interpret it as a description, standing in effect for any member of its equivalence class.

As we now have a means of talking about string forms and relations between them, we may offer a catalogue of morphological operations, construed as string relations. The list given here is adapted from Bauer (1988, p19ff).

(52)

Operation		*Source*	*Derived form*
Affixational	(prefix)	*stem*	*prefix+stem*
	(postfix)	*stem*	*stem+postfix*
Circumfixational		*stem*	*prefix+stem+postfix*
Infixational (or interfixational)		$stem_1+stem_2$	$stem_1+infix+stem_2$
Subtractive		$stem_1+stem_2$	$stem_1$
Zero-derivational		*stem*	*stem*
Intercalational (or transfixational)		$b+c+d$	$b+v+c+w+d$
Reduplicative		$x+stem+y$	$x+stem+stem+y$
Replacive		$x+y+z$	$x+w+z$
Suppletive		x	y
Metathetic		$w+x+y+z$	$w+y+x+z$

The distinction between "infixational" and "interfixational" operations cannot be made within this simple framework, as it makes reference to syntactic (or at least non-orthographic) information (namely whether the elements in question are syntactically the same, in the case of interfixational morphology, Bauer 1988, p24). Likewise the case of "super-", "supra" or "simulfixation", whereby some morphological relation is realized by some alternation in suprasegmental properties such as tone, cannot be properly represented in the orthographic domain alone. A further difficult case is that of reduplication where the reduplicated material is not string-identical to some other part of the item.

This concludes my survey of the formal background for this thesis. One point should be emphasised here. The systems of feature value logics and string descriptions both support the notion of subsumption. This similarity will be crucial in the development of Chapter 3.

2.4 Nonmonotonic systems in Linguistics

The aim of this section is first to discuss nonmonotonic devices that have been proposed, or implicitly used in linguistics, and their implications for the methodology of linguistic description. We will then go on to discuss the language DATR proposed by Gerald Gazdar and Roger Evans in recent publications (Evans and Gazdar 1989a,b).

Devices which introduce some kind of nonmonotonic behaviour in systems for linguistic description have been prevalent for a considerable period of time. Examples are most readily found in areas such as phonology, where the notion of *markedness* has been used to capture "preferences" for particular vowel systems. Languages of the world exhibit a preference for systems where vowels which are both back and high are also round. English u, as in "boot", is such a vowel. In comparison, front and high vowels tend *not* to be round. So, the vowel y found in French "bu" or German "Brüder" is relatively rare. These facts might be described by setting up a "default" rule of the following kind.

(53)

$$\begin{bmatrix} \text{BACK} & - \end{bmatrix} \rightarrow \begin{bmatrix} \text{ROUND} & - \end{bmatrix}$$

One of the most explicit examples of this is to be found in Chomsky and Halle's *The Sound Pattern of English.* In such a system, segments may be unspecified for a particular feature (i.e. they represent the unmarked case for that feature) and values are then filled in by default (cf. also Gazdar *et al* 1985, p30).

Many of the formalisms which developed such devices relied on procedural notions of well-formedness, and it is only with the recent concern in linguistics for stating well-formedness declaratively that the status of such formulations has been examined in any detail. In particular, Shieber (1986b) points out that devices used in formalisms such as LFG may fail to have a characterization in terms of a (first order) monotonic logical framework.

From the perspective of modern linguistic theory, the reasons why one might wish to introduce nonmonotonicity into a linguistic framework are two-fold. The first is difficult to quantify, but is reasonably summed up by the statement that few linguistic rules operate without exception. In other words, we believe of our linguistic statements that they hold true for the majority of cases and some special form of statement is required to prevent the use of a particular rule in an exceptional case. Of particular relevance to our discussion is the often irregular behaviour of morphological formation. Gazdar (1985b) points out that a mechanism which allows the overriding of regular formation offers a way of capturing the effect of 'blocking' (Aronoff 1976, also known as 'pre-emption', Clark and Clark 1979), that is, the existence of some irregular form, such as *went*, prevents the derivation of forms via the more regular rules, i.e. **goed*.

The second motivation is easier to quantify, and has to do with the *conciseness* of linguistic descriptions. It is concisely stated in the following quote from Pāṇini (Paribhāṣā 122): "Grammarians rejoice over the saving of the length of half a short vowel as over the birth of a son" (taken from P. Thieme's introduction to Shefts 1961). For example, Gazdar *et al* (1985) present a GPSG grammar for a considerable fragment of English, involving the statement of defaults over feature structure descriptions of categories. One *feature specification default* is:

(54) FSD 2: ~[CONJ]

which may be read "by default, a category has no value for the feature CONJ". The reason why such a statement is useful is that without it we should have to specify this information explicitly on all categories where it was required. The effect of this would be to increase considerably the size and number of statements in the grammar as a whole.

Under one interpretation, the two points of view described above are just opposite sides of the same coin. The extreme form of this position, although one to which I have not found any explicit adherents, claims that one of the defining characteristics of natural languages is their *structuring by subgeneralization*. That is, in stating what we believe to be a linguistic rule that describes an observable regularity, it is implicitly qualified by a statement to the effect that there may be exceptions to it and that these exceptions are not limited to some small finite (and therefore uninteresting) set. Now, from a methodological point of view, we do not want to make our descriptive statements in a system which allows the arbitrary defeating of statements. Otherwise, we are in the position of being unable to rely on the theory we construct actually predicting linguistic behaviour and of confining ourselves to the cataloguing of particular facts. In other words, the system is not generative in any currently accepted sense.

Two questions arise here. First, is the requirement of non-trivial prediction any different from what we would impose on non-linguistic theories? Second, are there any devices used in linguistic theories which guarantee that this property holds? It seems as if the answer to the first is clearly "no, and for the same reasons", and this prompts the further query whether there are nonmonotonic logics that have this property and how, in general, it may be guaranteed. (In the phonological cases discussed above, this question is of less importance as there is taken to be a small finite number of possible feature structures, and the procedurally defined effect of defaults may be calculated by hand). The answer to the second question is more concrete, if equally inconclusive.

2.4.1 The Elsewhere Condition

The *Elsewhere Condition* (EC) has been attributed by authors such as Kiparsky (1973) to the Sanskrit grammarian Pāṇini. The historical accuracy of this attribution is widely contested and we need not concern ourselves with this question here. Stated informally, the EC governs the applicability of rules on the basis of their formal properties—its purpose is to prevent the application of a general rule in exceptional cases. Its name derives from formulations in which exceptional cases are enumerated first and a final, general case is stated which holds "elsewhere", that is in all non-exceptional cases. Here I examine the possibility that a formal explication of the EC is possible in terms of subsumption.

Assuming, for convenience, that we may talk of linguistic rules as having an antecedent ϕ and a consequent ψ, the EC requires (at least) that, if two rules

(55) a $\phi \rightarrow \psi$
b $\phi' \rightarrow \psi'$

are (at some point) applicable and the situations described by ϕ are a proper subset of those described by ϕ' (possibly with further restrictions on the nature of ψ and ψ'), then rule (55a) applies while rule (55b) is forbidden to apply (either at this point or at any other point in the derivation).

The qualifications of the previous sentence arise from the different forms of the EC have been proposed. First, many such proposals have been made in the context of linguistic descriptions based primarily on a procedural notion of derivation. That is, rules apply in a fixed order and derivations may alter the values associated with features. Second, while apparently all formulations rely on the relative specificity of antecedents, they differ on the further conditions they apply. Perhaps the most classical interpretation, although one at odds with most conceptions of generative rules (but see Matthews, 1972 p194), proposes that rules are "grouped" in very much the standard manner of defining a mathematical function by cases. That is, the schematic form of statements is:[2]

(56) For some (abstract) linguistic rule:

1. If ϕ holds then also ψ
2. otherwise if ϕ' (which is more general than ϕ), then ψ'

In this case, we have effectively sidestepped the problem of determining those rules whose application may be subject to the EC, by enumerating them within the scope of some other expression. This problem has other possible solutions. Kiparsky

[2]As usual with discussions of the Sanskrit grammarians, disagreement is easier to find than agreement. Boudon (1938, p367) discusses one such grouping: "Le sūtra ainsi compris est un adhikāra (règle gouvernante) dont l'influence s'étend jusqu'à la fin de 5,2, i.e. sur toutes les règles des suffixes taddhita." Bloomfield (1927, p270) offers a similar point of view: "...the word 'and' shows the continuing validity ...up to this point, and the cessation of validity ...at this point of the word *na* "not" ..." These may be compared with Renou (1941-1942, p474): "Ainsi en Grammaire, où l'*adhikāra* initial est souvent perdu de vue à mesure qu'on avance dans le chapitre qu'il commande." (Page references here are to Staal 1972).

(1973) suggests that (in my terminology), given some input compatible with the antecedents of the two rules in question, either the consequents are identical or they are incompatible. The first of these conditions is probably unnecessary—if the competing rules have identical effects, it may not make any difference which rule is applied. (There may however be situations in phonological derivations where different effects might result.) The second states that the consequents may differ such that they are inconsistent. The case ruled out is that where the consequences are distinct but compatible. For instance, ψ and ψ' may assign values to disjoint sets of features. These stipulations are an attempt to capture the intuition that, if something like the EC is in operation, its use only makes sense in the context of rules "which are manifestations of the same linguistic phenomenon". Of course, this phrasing is very vague, but it seems to me that attempting to make more concrete the notion "manifestation of the same linguistic phenomenon" is unlikely to be a fruitful enterprise. As we will see in Section 3.1.1 and in the analyses presented thereafter, reasonable headway can be made without doing so.

The various proposals that fall under the heading of the EC are usefully reviewed in Janda and Sandoval (1984, Section 1.1). The sources they cite include Anderson (1971), Sanders (1974), Koutsoudas, Sanders and Noll (1974), and Kiparsky (1973, 1982). They state that Anderson's thesis of 1969 (Anderson 1971) is the first appearance of such a principle of rule application. In fact, Matthews (1965a, p164, p167 "Routine A") gives a description of the process of rule application which obeys precisely this principle:

> [I]n looking for the rule which applies at any particular stage of the derivation ..., the procedure must scan the subsection [= a group of rules, JHRC] in such a way that the possibility of applying a more general rule ... cannot be considered until the eligibility of each of its exceptions ... has first been considered and rejected. [Matthews 1972, p193]

Matthews suggests Lamb (1964), a source I have not been able to consult, as the first modern occurrence of such a formulation.

Janda and Sandoval (1984) themselves take a somewhat negative view of the utility and appropriateness of some version of the EC. Their claim in essence is that any use of an EC-style formulation is more appropriately captured, according to the details of particular cases, by the extrinsic ordering of phonological rules or by a weaker principle that "lexically-limited rules precede and pre-empt lexically-free ones" (1984, p24ff and pp43–50). As we saw in Section 2.1.1, there are perhaps reasons for wishing to move away from the first of these proposals, in order that our theories are less procedural in nature. The second I see as less objectionable, as it represents essentially the same claim about the organization of linguistic systems as that made by Bloomfield *inter alia* discussed in Section 1.5. That is, exceptions are characterized solely in the lexicon and are therefore idiosyncratic and uninteresting. This thesis is based on the assumption that this claim is not true.

A system for linguistic description which embodies some form of the EC has two properties worthy of note. First, we guarantee that any theory is non-trivially predictive, with some qualifications discussed below. Any set of rules which is governed by the EC will contain (at least) one most general rule, and it is this rule or rules that we might point to as representing the "widest" generalization. Other cases that fall within the scope of the set may be particular, trivial exceptions or exemplars of a potentially infinite subgeneralization. Furthermore, this most general rule may only be defeated by a more specific statement. We *cannot* defeat it by setting up an even more general rule, as any situation previously described by the less general rule will still be so described and it is therefore the less general that will "win".

The second property of interest is that, given some conditions to be discussed shortly, the EC may be seen as an abbreviatory technique. That is, any set of rules expressed in a formalism incorporating it may be transformed into another set where the operation of the EC is implicit. One condition we require here is that we may express arbitrary negative conditions in the antecedents of our rules. Suppose this holds, and we have a set of rules $\mathcal{T}$, governed by the EC, whose antecedents are $A = \phi_1, \ldots, \phi_n$. These antecedents will form a set which is partially ordered by the relation of subsumption (or logical consequence, see Section 2.3.1), $\langle A, \geq \rangle$, where $\geq$ has the standard properties, i.e. it is reflexive, antisymmetric and transitive.[3] If $\phi_i > \phi_j$ then there is some formula χ such that $\phi_i \wedge \chi$ is identical to ϕ_j. That is, χ is the information in virtue of which ϕ_j is more specific than ϕ_i. Equivalently, the conjunction of χ's negation and ϕ_i gives us a precise characterization of that class which the rule with antecedent ϕ_j may not apply to. Now, we may use the transformation described in (57) to relate a theory $\mathcal{T}$ which invokes the EC to another $\mathcal{T}'$.

(57) Let $\mathcal{T}$ be some theory which incorporates a form of the EC and let $A = \{\phi_1, \ldots, \phi_n\}$ be the set of antecedents in T. Let **exceptions**(ϕ) be the function:
exceptions(ϕ) $= \{\phi' | \phi' \in A \wedge \phi > \phi'\}$ if $\phi \in A$.
The corresponding theory $\mathcal{T}'$ not incorporating the EC is just like $\mathcal{T}$ except that, for all ϕ from A, if **exceptions**(ϕ) is non-empty
$\phi \wedge \bigwedge_{\psi \in \textbf{exceptions}(\phi)} \neg\psi$
replaces ϕ in $\mathcal{T}$ to give $\mathcal{T}'$.

This definition sums over all formulas that are subsumed by the formula in question and conjoins the negation of each of them with that formula. In other words, we require that the general case is further annotated to indicate explicitly that any of the specific cases may not hold.

As an illustration of the use of this transformation, consider the following set of rules:

[3] My intention here is to be general; any system which supports the notion of subsumption or logical consequence and permits negation will allow the following transformation to be defined over it. Importantly, feature structures and expressions in propositional calculus both fall into this category. The extension required to allow this to hold also of strings is discussed in Section 3.3.

(58) a $\phi \rightarrow p$

b $\phi \wedge \psi \rightarrow q$

c $\phi \wedge \chi \rightarrow r$

where $\mathbf{exceptions}(\phi) = \{\phi\wedge\psi, \phi\wedge\chi\}$. Performing the transformation given above to (58a) results in

(59) $\phi \wedge \neg(\phi \wedge \psi) \wedge \neg(\phi \wedge \chi) \rightarrow p$

Ignoring the consequent of this rule, we may allow the following simplification of the antecedent:

(60)

$\phi \wedge \neg(\phi \wedge \psi) \wedge \neg(\phi \wedge \chi)$	
$\phi \wedge (\neg\phi \vee \neg\psi) \wedge (\neg\phi \vee \neg\chi)$	De Morgan's law
$((\phi \wedge \neg\phi) \vee (\phi \wedge \neg\psi)) \wedge ((\phi \wedge \neg\phi) \vee (\phi \wedge \neg\chi))$	Distributivity
$(\phi \wedge \neg\psi) \wedge (\phi \wedge \neg\chi)$	Inconsistency
$\phi \wedge \neg\psi \wedge \neg\chi$	Distributivity and associativity

Only well-accepted logical equivalences have been used in this simplification.

The notion of *weakness of antecedents*, invoked by Nute (1986), is clearly related to the EC. In making the statement "matches burn when struck", we are making a statement with obvious exceptions, since we can easily assert, without apparent contradiction, that "wet matches don't burn when struck". We can of course make the further statement that "waterproof matches burn when struck, even if they are wet". The structure of these statements can be summarized as in (61):

(61) a $a \rightarrow p$

b $a \wedge b \rightarrow \neg p$

c $a \wedge b \wedge c \rightarrow p$

In other words, as we weaken the antecedent of an implication, so we change, non-monotonically, the conclusions that can be drawn from the implication. Following Nute's argument, even though the antecedents of an implication are satisfied, there may be situations in which detaching the consequent may not be justified. A structurally identical argument can be made in the context of the morphology of English. I will state the argument informally:

(62) a If a verb α is of the form ω, then its progressive form is the concatenation of ω and "ing".
b If a verb α is of the form ω concatenated with "e", then its progressive form is the concatenation of ω and "ing".
c If a verb α is of the form "age", then its progressive form is the concatenation of "age" and "ing".

Van Benthem (1986) points out that iterated inference in systems where modus ponens is conditionalized with respect to other possible rules of inference involves the danger of unsoundness. That is, a particular deduction may be invalid in the case where inference involves more than one step. The following example is a simple demonstration of this.

(63) a $a \rightarrow b \wedge p$
b $a \wedge b \rightarrow \neg p$

That is, if we know a, we may by (63a) infer $a \wedge b \wedge p$. However, in this case we may by (63b) infer $a \wedge b \wedge p \wedge \neg p$. This is clearly undesirable in a system of logical inference and, as I shall use statements of this form in analyses below, it is important to indicate why this will not cause problems in their interpretation. Crucially, the systems I deal with below are concerned with the existence of "objects", in particular pairs of orthographic and morphosyntactic specifications. That is, they allow the inference of the existence of such an object but do not place any global constraints on the structure of objects. The problem described above would occur if we allowed statements like those above which were well-formedness conditions on all lexical entries. It is interesting, but unfortunately outside of the scope of this thesis, to consider under what circumstances more general systems involving this form of reasoning remain sound.

One aspect of this example is, however, worth considering in more detail. Consider the result of applying the transformation described in (57) to the above set of statements. This results in the following statements:

(64) $a \wedge \neg b \rightarrow b \wedge p$

Note that under this transformation (63a) results in the inconsistent formula (64). One possible line of research in this area would determine what logical systems allowed statements involving "Elsewhere Condition" style effects, while only giving rise to consistent theories under the transformation outlined above.

2.4.2 Defaults in Unification-Based Formalisms

While the use of defaults has been discussed occasionally in the literature on unification-based formalisms, we have not yet seen comparable attempts at their integration within a formally well-founded system, despite the comments in Shieber (1986b, pp60ff) and the discussion in 2.4 about the utility of default statements.

In the rest of this section, after reviewing some of the fundamental concepts in this area, we will first consider some of the reasons why there has been comparatively little work on the integration of defaults with linguistic formalisms that fall under the rubric of logic grammars or unification-based formalisms. We then review the proposals that do exist in this area and the linguistic data that motivate them. Finally, we examine the language DATR proposed by Evans and Gazdar (1989a,b). Even though this language might not be considered a unification-based formalism under the definitions I give below, it represents the most substantial attempt to provide a logical semantics for a linguistic formalism involving the default inheritance of values and should, at the very least, be suggestive of developments to be expected in this area.

We may identify two main reasons for the lack of proposals which aim to integrate defaults with unification-based formalisms. First, most work which provides logical interpretations for grammatical formalisms (discussed in detail above) is relatively recent and has concentrated on aspects of these formalisms which are closely related to well-understood logical formalisms. As the field of nonmonotonic logic, which is presumably the area of logic that would support such work, is in something of a state of flux at the moment, it is unsurprising that little work has been done that attempts to link these two areas.

A second point is that, as with other aspects of linguistic description, researchers in linguistics who make use of defaults have tended to be satisfied with a procedural characterization of their behaviour, assuming some (typically unspecified) algorithm for the instantiation of features. In this situation, as the intended interpretation is not obvious, it is unclear how to achieve a formalization of the system. Furthermore, it may be difficult to translate attractive analyses proposed within such systems into formalisms with a declarative, monotonic semantics without substantial revision.

This leads to a further, more practical reason why defaults have not figured largely in the formalisms presented to date, and this has to do with the efficient computational interpretation of nonmonotonic systems. From an implementational point of view, the problem arises that in the general case it is not possible to determine whether a default statement can be correctly applied until it is certain that no further instantiation of feature structures may occur. The statements below, viewed as defaults, illustrate this.

(65)

$$\left[\textsc{class} \quad \text{strong} \right] \rightarrow \left[\textsc{gender} \quad \text{feminine} \right]$$

$$\begin{bmatrix} \textsc{class} & \text{strong} \\ \textsc{subclass} & \text{mixed} \end{bmatrix} \rightarrow \left[\textsc{gender} \quad \text{masculine} \right]$$

$$\begin{bmatrix} \textsc{class} & \text{strong} \\ \textsc{subclass} & \text{mixed} \\ \textsc{number} & \text{plural} \end{bmatrix} \rightarrow \left[\textsc{gender} \quad \text{feminine} \right]$$

In this example, the implications are ordered by the "weakness" of their antecedents, (cf. Nute 1986). Even if, at some point in the derivation, the antecedent condition of the first is met by some feature structure F which is consistent with the consequent, we are still not in a position to infer that the consequent is also true of F. This is for two reasons. First, we cannot be certain that F will remain consistent with the consequent. Second, the second statement indicates that other conflicting defaults may also be applicable in case F is appropriately instantiated.

The implication of this example is that the use of defaults appears to have undesirable computational properties. Testing for the applicability of defaults may be costly and will not in general lead to a reduction of the number of derivations that have to be considered in analyzing a sentence.

2.4.3 Proposals to date

Defaults in GPSG

The most explicit theory of defaults for a linguistic formalism is presented in Gazdar *et al* (1985), p. 29ff, 100–104. Following usage originating in the theory of phonological categories, the specification of well-formed GPSG categories involves the statement of default values for features. That is, a feature may have associated with it a value that it assumes if there is no reason why it should not have that value (borrowing a locution from Gazdar *et al* 1985, p. 30). A typical *feature specification default*, seen above as (54), is:

(66) FSD 2: ~[CONJ]

which states that, all other things being equal, categories should not be specified for the feature CONJ.

The use of FSDs in GPSG has some crucial differences to the types of system we wish to consider here. Most importantly, GPSG lacks a general information-combining operation. The definition of well-formedness proceeds via the definition of all well-formed substructures. The application of defaults is performed by considering all *candidate* instantiations and removing those which fail to adhere to a default, if at least some other instantiations respect it. (This description is somewhat simplified.) While the proposals that have originated from GPSG have been suggestive of further work in this area (cf. Shieber 1986a), they do not help us with the general problem of providing a useful notion of default for more dynamic systems.

Priority union in LFG

Kaplan (1987, p180) proposes the addition of an operator called *priority union* to the LFG formalism which allows the combination of feature structures containing possibly conflicting information. One way of describing the behaviour of this operator is that it maximizes the information contained in the feature structures it combines. However, if the feature structures are incompatible, the operator "gives priority to one of them"—any values in other feature structures which conflict with the feature structure given priority are ignored. The following example illustrates its use (Kaplan's (22)), where '/' is the priority union operator:

(67)

$$\mathrm{A} = \begin{bmatrix} \text{Q} & r \\ \text{S} & t \\ \text{U} & v \end{bmatrix} \mathrm{B} = \begin{bmatrix} \text{Q} & m \\ \text{S} & t \\ \text{P} & l \end{bmatrix} \mathrm{A/B} = \begin{bmatrix} \text{Q} & r \\ \text{S} & t \\ \text{U} & v \\ \text{P} & l \end{bmatrix}$$

From this example, we can see that the operator is non-commutative. Here the feature structure A is given priority. Kaplan suggests that the operator is read "A in the context of B" or "A given B" and that B may be taken to supply default values for features unspecified in A.

It is worth pointing out that Kaplan's version of priority union appears to have a simple characterization in terms of the formal apparatus discussed in the previous section. First, I enumerate some of the properties we may suppose / to have:

(68) a $\mathrm{A} \geq \mathrm{A/B}$
b $\mathrm{B} \geq \mathrm{A} \rightarrow \mathrm{A/B} = \mathrm{A}$
c $\mathrm{A} \geq \mathrm{B} \rightarrow \mathrm{A/B} = \mathrm{B}$ unless $\mathrm{B} = \perp$
d $\mathrm{B} = \perp \rightarrow \mathrm{A/B} = \mathrm{A}$
e $\mathrm{B} = \neg\mathrm{A} \rightarrow \mathrm{A/B} = \mathrm{A}$
f $\mathrm{A} = \perp \leftrightarrow \mathrm{A/B} = \perp$
g for some C, $\mathrm{A/B} = \mathrm{A} \wedge \mathrm{C}$ where $\mathrm{C} \geq \mathrm{B}$

In other words, if B is inconsistent or a more general feature structure than A or if it represents the negation of A, then it makes no contribution to the priority union of the two feature structures. If A is more general than B, then the priority union of the two feature structures is just B, unless B is itself inconsistent. A/B should be inconsistent only if A is. In any case, A/B represents some feature structure which is subsumed by A and some other feature structure C which also subsumes B. What is of interest, of course, is how we may characterize the feature structure C.

There are essentially two cases that we need to consider, according to whether A and B taken together are inconsistent. The case in which they are mutually consistent is easily described. In this case, we may state:

(69) $\mathrm{A} \wedge \mathrm{B} > \perp \rightarrow \mathrm{A/B} = \mathrm{A} \wedge \mathrm{B}$

and we may easily verify that this proposal conforms to the desired properties in (68). On the other hand, if A and B are inconsistent, I propose to use a construction which examines feature structures which are more general than B and forms the disjunction of those which meet a further condition to be discussed below. This proposal is similar to those in nonmonotonic logic for calculating the effect of defaults by examining consistent subsets of a theory (cf. Rott 1990, and references therein). I therefore propose the following as a possible definition of priority union:

(70)

$$\mathrm{A/B} = \begin{cases} \mathrm{A} \wedge \mathrm{B} & \text{if } \mathrm{A} \wedge \mathrm{B} > \perp \\ \mathrm{A} \wedge \bigvee\{\mathrm{C} \mid \; \mathrm{C} \in [\mathrm{B}, \top] \text{ and } \mathrm{C} \wedge \mathrm{A} > \perp \text{ and} & \\ \qquad\qquad\quad \forall \mathrm{D}(\mathrm{C} > \mathrm{D} \rightarrow \mathrm{D} \wedge \mathrm{A} = \perp)\} & \text{otherwise} \end{cases}$$

The first line of this definition states that the priority union of two feature structures is their conjunction if they are consistent, as discussed above. If they are inconsistent, then we consider the set of feature structures C that lie between B and $\top$, with the following proviso: feature structures need not be considered in the case where there is a more specific feature structure, also more general than B, which is consistent with A. We may think of the second condition as "drawing a line" above the feature structures subsuming B which are inconsistent with A, as

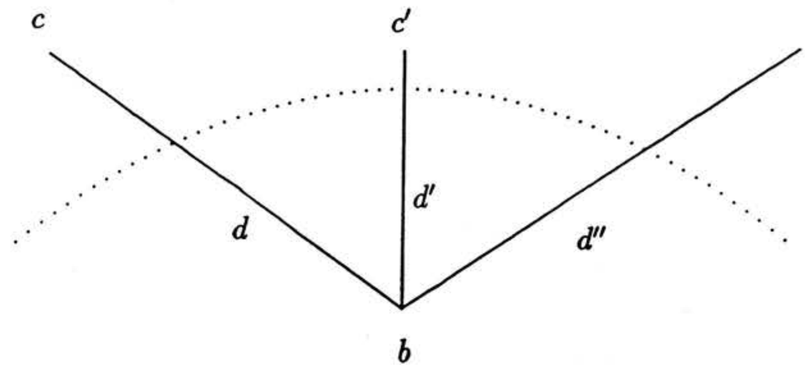

Figure 2–3: Relations between feature structures in priority union

shown in Figure 2–3. That is, the second case of the definition imposes a specificity condition on possible values for C. C must be consistent with A, but any more specific element must be inconsistent with A. The feature structure with which A is conjoined is then the disjunction of elements which obey this condition.

We may now see to what extent the behaviour of this definition of A/B conforms to the desiderata of (68). Cases (68b) and (68c) follow unproblematically as they fall under the first case of the definition above. For (68d), we may argue that, as $B = \bot$, the second conjunct will be the disjunction of all feature structures with which A is consistent. This we may identify with A. Property (68e) is problematic under the definition given above. To see this, take $A = \neg(D \wedge E)$ and $B = (D \wedge E)$. Here, $A = \neg B$ and so, under a classical construal of negation at least, $B = \neg A$. The interval $[B, \top]$ then contains

(71) $\{D \wedge E, D, E, D \vee E, \top\}$

Of these, we may discard $D \wedge E$ as it is inconsistent with A. On the other hand, because the elements D and E are by themselves consistent with A, $\top$ and $D \vee E$ are ruled out in virtue of being more general than D or E. Therefore the set of elements we need to consider is just $\{D, E\}$ and the definition results in:

(72) $A/B = \neg(E \wedge D) \wedge (D \vee E)$

This formula requires one of E and D to be true, whereas A does not. So, despite the fact that A is the negation of B, A/B is more specific than B. Whether or not this result is desirable is a question I shall leave open here.

The biconditional in (68f) follows directly from the definition. If $A = \perp$, then either of the two cases in (70) will result in $\perp$. If $A/B = \perp$, then either $A = \perp$ or every disjunct of the right hand conjunct of the second case in (70) must be inconsistent with A. But, by that definition, all disjuncts are consistent with A and so the disjunction as a whole must be consistent with A.

Properties (68c) and (68d) imply, naturally enough, that this formulation of priority union is nonmonotonic. As such, it only makes sense to consider values that might result from A/B when it is known that A will not become further specified. In other words, this formulation requires priority union to be a *final function* in the sense of Shieber (1986b, p43), that is a function whose value can only be computed at the end of a derivation.

The informal observations above lead to a more general question, namely whether the definition given in (70) can be reexpressed in terms of the standard operations of a Heyting or Boolean algebra, as discussed in Section 2.3.2. We may start by noting that if A and B are inconsistent, then the following also holds:

(73) $\neg A \geq B$

It might appear the operation of relative pseudocomplementation in a Heyting algebra holds out some hope, as we might argue that, in the second case of the definition, we are interested in the feature structure which represents the "difference" between $\neg A$ and B. We might then be tempted to say that A/B is the conjunction of A with the feature structure which, unified with $\neg A$, gives B:

(74) $A/B = A \wedge (\neg A \Rightarrow B)$

This formulation might seem to be appropriate, given the informal characterization of the relative pseudocomplementation $A \Rightarrow B$ as "the least feature structure which, unified with A, yields B". (cf. Section 2.3.2). However, the following theorem (Goldblatt 1979, p181) shows that this approach will not be successful:

(75) $\neg A \leq A \Rightarrow B$

Substituting $\neg$ A for A, we may infer

(76) $\neg\neg A \leq \neg A \Rightarrow B$

and so

(77) $A \wedge (\neg A \Rightarrow B) = A$

(This is in fact a theorem of both Boolean and Heyting algebras). So the formulation of (74) is insufficient, as it does not result in the inclusion of any information from B in A/B.

The consequence of these results is to show that the formulation I have proposed captures precisely the desired behaviour of /. Let us now reconsider Kaplan's example ((67), repeated here as (78)) to show how the definition of (70) works in practice.

(78)

$$\mathrm{A} = \begin{bmatrix} \mathrm{Q} & r \\ \mathrm{S} & t \\ \mathrm{U} & v \end{bmatrix} \mathrm{B} = \begin{bmatrix} \mathrm{Q} & m \\ \mathrm{S} & t \\ \mathrm{P} & l \end{bmatrix} \mathrm{A/B} = \begin{bmatrix} \mathrm{Q} & r \\ \mathrm{S} & t \\ \mathrm{U} & v \\ \mathrm{P} & l \end{bmatrix}$$

Let A and B be as in (78). Then, we need to consider all feature structures which lie between B and $\top$. These are:[4]

---

[4]In the following example, I have omitted certain disjunctive feature structures, to simplify the exposition. These feature structures are all ruled out in virtue of the second condition in the definition of priority union.

(79)

$$\{\top, [\textsc{q}\ m], [\textsc{s}\ t], [\textsc{p}\ l], \begin{bmatrix} \textsc{q} & m \\ \textsc{s} & t \end{bmatrix}, \begin{bmatrix} \textsc{q} & m \\ \textsc{p} & l \end{bmatrix}, \begin{bmatrix} \textsc{s} & t \\ \textsc{p} & l \end{bmatrix}, \begin{bmatrix} \textsc{q} & m \\ \textsc{s} & t \\ \textsc{p} & l \end{bmatrix}\}$$

Of these, all but the feature structure in (80) violate the second condition in (70), either in virtue of contradicting A or because there is some more specific feature structure which does not contradict A.

(80)

$$\begin{bmatrix} \textsc{s} & t \\ \textsc{p} & l \end{bmatrix}$$

So, as required,

(81)

$$\mathrm{A/B} = \begin{bmatrix} \textsc{q} & r \\ \textsc{s} & t \\ \textsc{u} & v \end{bmatrix} \wedge \bigvee \left\{ \begin{bmatrix} \textsc{s} & t \\ \textsc{p} & l \end{bmatrix} \right\}$$

$$= \begin{bmatrix} \textsc{q} & r \\ \textsc{s} & t \\ \textsc{u} & v \\ \textsc{p} & l \end{bmatrix}$$

The formulation of priority union given above is correct in this case. A more general demonstration of its correctness is still required in the light of (72) and other considerations of its desired behaviour.

2.4.4 DATR

DATR was introduced by Evans and Gazdar (1989a,b) as a language for the description of objects, in particular lexical entries, in a form suitable for a theory such as GPSG, HPSG or LFG. Evans and Gazdar (1989a) concentrates on the rules of inference utilized by the language, while Evans and Gazdar (1989b) gives a semantics for it. Further examples of the use of DATR are given in Evans and Gazdar (1990).

One way of characterizing DATR is that its basic operation is *information-inheriting*, rather than *information-combining*. That is, one may state of an object that it has the same features as some other object, but such a statement is always qualified in that a local specification of some feature may prevent the inheritance of a value from elsewhere. Typical DATR statements take the form:

(82) $\mathbf{Node}_i{:}\langle \text{path}_j \rangle == \mathbf{Node}_k{:}\langle \text{path}_l \rangle$ or
$\mathbf{Node}_i{:}\langle \text{path}_j \rangle == \textit{value}$

(Various abbreviatory mechanisms allow a more concise representation than that shown, but will not be discussed here). The first of these forms may be read as "the value of $\langle \text{path}_j \rangle$ at $\mathbf{Node}_i$ is inherited from $\langle \text{path}_l \rangle$ at $\mathbf{Node}_k$". The second states that the value of $\langle \text{path}_j \rangle$ at $\mathbf{Node}_i$ is *value*.

With this syntax, we may state DATR theories of the following kind:

(83) $\mathbf{Verb}{:}\langle \text{cat} \rangle == v$
$\mathbf{Verb}{:}\langle \text{aux} \rangle == -$
$\mathbf{Aux}{:}\langle\rangle == \mathbf{Verb}{:}\langle\rangle$
$\mathbf{Aux}{:}\langle \text{aux} \rangle == +$

The first statement here says that the value for the path $\langle \text{cat} \rangle$ at **Verb** is v, the second that the value for $\langle \text{aux} \rangle$ at that node is $-$. The effect of the third line is to state that the node **Aux** inherits specifications from **Verb**. The symbol $\langle\rangle$ represents the empty path; as such, it is a *prefix* of all other paths. The fourth statement here will allow us to infer that at the node **Aux**, the value for the path $\langle \text{aux} \rangle$ will be $+$. This is in contrast to its value at the node **Verb**, where it is $-$. On the other hand, as **Aux** is not specified for the path $\langle \text{cat} \rangle$, we may infer a value of v for that path at that node on the basis of the statement of inheritance from **Verb**.

A DATR theory may be *queried* or *interrogated* by asking for the value of a given path at a given node. We have just seen three such queries, namely

(84) **Aux**:⟨aux⟩ = +
Verb:⟨aux⟩ = -
Aux:⟨cat⟩ = v

where the symbol '=' represents the *extensionalization* of a query. DATR therefore provides the notion of the evaluation of a query at a node. The examples above are all examples of *local* inheritance—the answer to a query is computed by following the stated inheritance relations from the node which is queried until a node is found which is specified for the path in question. DATR also offers a notion of *global* inheritance, on the basis of specifications such as

(85) **Verb**:⟨morphology perfective⟩ = ed
Verb:⟨perfect⟩ = ("⟨root⟩" "⟨morphology perfect⟩")
Be: ⟨⟩ == **Verb**
Be:⟨morphology perfect⟩ == en
Be:⟨root⟩ == be
Walk: ⟨⟩ == **Verb**
Walk:⟨root⟩ == walk

Here the path "⟨root⟩" is a global path. (This example also illustrates the use of lists delimited by parentheses to build structured representations.) We may gloss these statements as:

(86) The perfective morphology of a verb is "ed".
The perfective form of a verb consists of its root together with its perfective morphology.
The verb "be" has the perfective morphology "en" and the root "be".
The verb "walk" has the root "walk".

In the evaluation of a query at some node $\mathbf{N}_i$, we may, as said before, examine the value of paths at other nodes to determine the result of a query. Global paths differ from local paths in that they are evaluated at the node that was originally queried and this node may be different to the node which is currently being examined. Thus, if we interrogate the DATR theory shown in (85) for the value of

(87) **Be**:⟨perfect⟩

evaluation of this query will proceed via the evaluation of the further queries:

(88) **Verb**:⟨perfect⟩
Be:⟨root⟩
Be:⟨morphology perfect⟩

Note that the node at which the path ⟨root⟩ is queried is **Be** from the original query (87). The result of the evaluation of the query is then:

(89) **Be**:⟨perfect⟩ = (be en)

which may be contrasted with the query,

(90) **Walk**:⟨perfect⟩ = (walk ed)

In this example and more generally, global inheritance provides a way for including information originating at some node $\mathbf{N}_i$ within a structure that is inherited at $\mathbf{N}_i$ from some other node.

One point that it is worth emphasizing in this context is that DATR avoids the well-known "Nixon diamond" problem of conflicting multiple inheritance by requiring the source of inherited information to be stated explicitly and uniquely. Thus, the statements below do not constitute a consistent DATR theory if $i = u$ and $j = v$, unless $k = w$ and $l = x$.

(91) $\mathbf{Node}_i$:⟨path_j⟩ == $\mathbf{Node}_k$:⟨path_l⟩
$\mathbf{Node}_u$:⟨path_v⟩ == $\mathbf{Node}_w$:⟨path_x⟩

This should help to show why DATR does not have an information-combining operation. If we were able to state an identity between two objects in a DATR theory, we would have to require either that no statements violated the restriction stated above or that some other provision, perhaps akin to priority union, were made to determine the specification that results from such a statement.

The use of explicit inheritance sets DATR apart from the majority of formalisms developed for linguistic description, Hudson (1985) being the other obvious example. Furthermore, the combination of local and global inheritance provides a powerful mechanism for the concise description of a variety of phenomena, evidenced in the extensive analyses in Evans and Gazdar (1990).

I will close this section with a consideration of the differences between an Elsewhere Condition approach, as discussed in Section 2.4.1, and one framed in DATR. It is, I think, clear that DATR provides a simple way of representing EC-style pre-emption (cf. also the comments in Evans and Gazdar (1990, p1)). If one has a theory where the EC is required to prevent overgeneration, one may translate it into a DATR theory by associating nodes with formulas. Let us assume a function f which represents this translation and investigate some of the properties f should have. If some formula ϕ preempts another ϕ', then we arrange for f(ϕ) to inherit from f(ϕ'). Furthermore, f has to specify some suitably named path at f(ϕ) and f(ϕ'), so that, while f(ϕ) in general inherits properties from f(ϕ'), the specification of that path at f(ϕ) will prevent inheritance in the case of interest.

For concreteness, the previous example (87) of English perfective morphology might find expression in an EWP framework (see Section 2.1.2) as:

(92)

$$\underset{X}{[+\text{perfect}]} \rightarrow X + \text{ed}$$

$$\underset{\text{be}}{[+\text{perfect}]} \rightarrow \text{be} + \text{en}$$

We may note here that DATR expresses more readily the generalization that suffixation is the only operation by which the perfect form is realized in these examples.

Note that the use of explicit rules is replaced in DATR with statements of inheritance between nodes. That is, information about inheritance is represented explicitly. This is to be contrasted with the system I develop below, where inheritance is determined implicitly on the basis of informational content. One possible disadvantage of this form of translation into DATR is that information may be possibly left implicit within a DATR theory. The obvious advantage is that DATR provides an expressive formalism with a well-understood interpretation. This may not be the case with formalisms that allow the arbitrary defeating of statements.

2.5 Summary

In this chapter, we have reviewed a large body of research originating in different areas which inform our study of morphology. In particular, we have reviewed some previous work which gives formal content to the notions of paradigm and morphological relations and we have seen some of the difficulties that result from attempting to construe this work in the light of formal systems for linguistic description based on logics of partial information. In the following chapter, I shall build on the concepts and techniques discussed here, providing novel definitions of "paradigm" and "lexical relation".

Chapter 3

Grammars for Lexical Description

In this chapter I will present a system for lexical description which has some of the properties of the formalisms discussed in the previous chapter. The system will be *paradigmatic*; it will characterize relations between morphological forms on the basis of relation between an abstract *paradigmatic word* and the explicit statement of forms that are related to that word. Objects will be characterized by *descriptions* with a logical interpretation. It will also be *nonmonotonic*; the Elsewhere Condition will be invoked to ensure that the derivation of items associated with irregularity is correct. A further nonmonotonic operation of *inheritance* and other abbreviatory mechanisms will be introduced to allow the more concise representation of morphological information.

I will follow essentially the style of presentation used in the formalization of systems such as context-free grammars (e.g. Aho and Ullman 1972). That is, I shall describe the set of statements that define a particular grammar and provide a definition of *derivability*. The set of objects defined by such a grammar is then the closure of these statements under derivability.

After introducing the different kinds of objects recognized by the system, I define the central notion of derivability via a paradigm. I then consider a number of objections which arise from this definition, and consider various enhancements that might counter them.

3.1 The elements of a paradigmatic grammar

3.1.1 Descriptions

I now begin the catalogue of elements which form part of a paradigmatic description. I start by reprising the definition of strings from Section 2.3.4 and then define morphosyntactic descriptions in terms of formulas in propositional calculus. I then combine these descriptions to provide a definition of *lexical specifications*, which are partial descriptions of words. Relations between morphosyntactic descriptions are represented as *lexical rules*. Relations between lexical specifications are represented using *paradigms*. Paradigms allow the *derivation* of lexical specifications and I discuss two possible definitions of derivability. This section concludes with some examples from the morphology of English.

With the caveat of Section 1.3, I take the domain of orthographic objects to consist of strings of characters. That is, I assume that the orthographic objects which form part of our morphological description are exhaustively characterized in terms of a set of characters, a set of variables and an associative operator. Following the definitions and notational conventions of Section 2.3.4, let C be a finite set of characters and V a countably infinite set of variables. A *string* is then constructed from the elements of C combined via +, while a *string specification* or *string form* may contain elements from C or V. The operator + represents the concatenation of strings, and obeys the axiom A (repeated from 2.(41)):

(93) A: $x + (y + z) = (x + y) + z$

Morphosyntactic descriptions will be constructed from a finite set of *morphosyntactic properties*. These will be represented below in the form active, base, ... In addition to any properties required by a grammar, I assume the existence of two properties true and false, the first of these being equivalent to any tautology, the second to the negation of any tautology. A morphosyntactic description is then just a formula, in the sense of propositional calculus. From string and morphosyntactic descriptions we may construct *lexical specifications*, that is, combinations which describe both orthographically and morphosyntactically.

3.1.2 Lexical specifications

A *lexical specification* is a pair, consisting of a string specification, σ, and some formula ϕ involving grammatical properties, which I will write as $\sigma : \phi$. A *lexical entry* is just like a lexical specification except that σ is constrained to be a string, i.e. it contains no elements taken from the set V of string variables. I assume for any grammar the existence of a finite set of lexical entries. I will term this set the *base lexicon*.

(94) A lexical specification $\sigma : \phi$ subsumes another $\sigma' : \phi'$ ($\sigma : \phi \geq \sigma' : \phi'$) iff $\sigma \geq_s \sigma'$ and $\phi \geq \phi'$.

(In other words, $\sigma' : \phi'$ contains at least as much orthographic and morphosyntactic information as $\sigma : \phi$).

As with the definition in (50), the relation of strict subsumption $>$ requires non-identity.

(95) A lexical specification $\sigma : \phi$ strictly subsumes another $\sigma' : \phi'$ ($\sigma : \phi > \sigma' : \phi'$) iff $\sigma : \phi \geq \sigma' : \phi'$ and $\sigma >_s \sigma'$ or $\phi > \phi'$.

To exemplify, the following examples are of a lexical specification and a lexical entry. Note that the former subsumes the latter.

(96) a w+s:verb $\wedge$ finite
b walks:verb $\wedge$ finite $\wedge$ intransitive

The unification of two lexical specifications $\sigma : \phi \approx \sigma' : \phi'$ is defined as follows:

(97) $\sigma : \phi \approx \sigma' : \phi' =_{def} \sigma \wedge_s \sigma' : \phi \wedge \phi'$

Thus the unification of (98a) and (98b) is (98c):

(98) a w+s:verb $\wedge$ finite
b walk+s:verb $\wedge$ intransitive
c walks:verb $\wedge$ finite $\wedge$ intransitive

As discussed in Section 2.3.4, we here assume that the unification of two strings is unique, that is, the conjunction implies a single mgu.

I shall be strict in my terminology with respect to lexical specifications, lexical entries and *lexical items.* The first of these is a general term, covering any object that falls under the definition given above. A lexical entry is any lexical specification that occurs in the base lexicon. A ***lexical item*** **is any lexical specification which is generated by the grammar. Further restrictions on what can count as a** lexical item are made below.

Some comment may be useful here to relate the definitions above with the concepts of "word-form", "lexeme" and "word", introduced in Section 2. We may identify the base lexicon with the set of lexemes. In this case, my proposal follows Anderson (1982) rather than Matthews (1972) in taking lexemes to be complex specifications rather than indivisible elements. We could of course introduce Matthews' notion by giving names to each element of the base lexicon. Little benefit would result from so doing. Despite the absence of lexemes as objects in the formalism, I believe it is fairly faithful to Matthews' formulation to consider lexical specifications as grammatical words. They may of course be underspecified in ways which Matthews' formulation does not allow—the nature of that underspecification is the subject of this thesis. We may define "word-form", with similar qualifications, as the string specification associated with a lexical specification.

3.1.3 Lexical rules

We have seen that a number of kinds of statements have been postulated to describe relations that hold between lexical items. For example, in an atransformational setting (Section 2.1.1), a lexical rule can do no more than further specify a given representation. In the more traditional view seen in 2.(3), it may represent an arbitrary transformation of some lexical representation. I aim accordingly to produce a formalization which covers both of these cases. Let us consider the second case. There are two requirements we will wish to make of the behaviour of lexical rules. In order for a lexical rule to apply, it must meet the specification of the rule's input. Furthermore, the result of application is computed on the basis of those properties of the rule's input which "do not change" and those properties that are the effect of the rule. For example, if one assumed lexical entries for verbs to bear the property **base** and wished to transform this representation into another bearing the property **progressive** in place of **base**, the following rule might be appropriate:

(99) base $\rightarrow$ progressive

The next question to address is how to characterize those properties which are constant under application of a rule. This I propose to achieve by defining a function **invariant**, which describes the "difference" between two specifications, one of which is more informative than the other. That is, in the case where some specification subsumes another, **invariant** defines the specification which, conjoined with the more general, yields the more specific. (It might be thought that the operation of relative pseudocomplementation is of use here. The discussion in Section 2.4.2 to do with example 2.(74) gives an indication why this is not the case.)

This discussion motivates the following definition for lexical rules. A *lexical rule* is a named pair **rule** $=\langle\psi, \psi'\rangle$, where ψ, ψ' are formulas in propositional calculus, and represents a mapping between such formulas. I will refer to ψ and ψ' as the *antecedent* and *consequent* of such a rule. The interpretation of a rule with respect to grammatical properties is given by the following definitions:

(100) Given a lexical item $\sigma : \phi$, and a lexical rule, **rule** $=\langle\psi, \psi'\rangle$, if $\psi \geq \phi$ then **rule** relates ϕ to another formula ϕ' in the following way:
$\phi' = \mathbf{invariant}(\phi, \psi) \wedge \psi'$.

If it is not the case that $\psi \geq \phi$ then the result of applying **rule** to ϕ is undefined. The function **invariant** then has the following definition, in terms of the intervals between formulas (cf. 2.(35)):

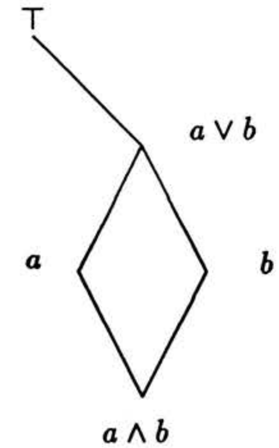

Figure 3–1: The determination of the function **invariant**

(101) $\textbf{invariant}(\phi, \psi) = \bigwedge([\phi, \top] - ([\phi, \psi] \cup [\psi, \top]))$

where $-$ is the operation of set complement.

Figure 3–1 illustrates the working of this definition, taking $\phi = a \wedge b$ and $\psi = a$. In this case,

(102)

$$\begin{array}{rcl} \textbf{invariant}(\phi, \psi) & = & \bigwedge([a \wedge b, \top] - ([a \wedge b, a] \cup [a, \top])) \\ & = & \bigwedge(\{a \wedge b, a, b, a \vee b, \top\} - (\{a \wedge b, a\} \cup \{a, a \vee b, \top\})) \\ & = & \bigwedge(\{a \wedge b, a, b, a \vee b, \top\} - \{a \wedge b, a, a \vee b, \top\}) \\ & = & \bigwedge(\{b\}) \\ & = & b \end{array}$$

The purpose of these definitions, then, is to characterize those parts of a formula which "do not change" under the application of some rule. Crucially, the use of the function **invariant** means that we may *defeat* properties associated with a particular specification. That is, no property mentioned in the antecedent of a rule appears in the output of that rule, unless it also appears in the consequent of the rule. (This formulation may be compared with the definition in Calder (1988), where a treatment in terms of sets of properties and set complement is offered.

The algebraic approach is preferred here as it is easier to relate this system to other proposals in the literature.)

Note that, in this formulation, a lexical rule is a function: the formula ϕ' is unique for any pair of ϕ and ψ. The use of conjunction over all the relevant formulas guarantees this. Of course, the function is nonmonotonic with respect to subsumption, as the following statement does not necessarily hold:

(103) $\phi \geq \phi'$ and $\psi \geq \psi' \rightarrow \mathbf{invariant}(\phi, \psi) \geq \mathbf{invariant}(\phi', \psi')$

To represent the application of a lexical rule $\mathbf{rule} = \langle \psi, \psi' \rangle$ to a formula ϕ, I will use the shorthand given below.

(104) $\mathbf{rule}(\phi) = \mathbf{invariant}(\phi, \psi) \wedge \psi'$

Application of the following lexical rules in (105) is illustrated in (106)

(105) a $\mathbf{progressive} = \langle \mathsf{base}, \mathsf{progressive} \wedge \mathsf{non\text{-}finite} \rangle$
b $\mathbf{passive} = \langle \mathsf{past} \wedge \mathsf{participle} \wedge \mathsf{verb}, \mathsf{passive} \wedge \mathsf{participle} \wedge \mathsf{verb} \rangle$

(106) a $\mathbf{progressive}(\mathsf{verb} \wedge \mathsf{base}) = \mathsf{verb} \wedge \mathsf{progressive} \wedge \mathsf{non\text{-}finite}$
b $\mathbf{passive}(\mathsf{past} \wedge \mathsf{participle} \wedge \mathsf{verb} \wedge \mathsf{transitive}) =$
$\mathsf{passive} \wedge \mathsf{participle} \wedge \mathsf{verb} \wedge \mathsf{transitive}$

On the other hand, the following are undefined.

(107) a $\mathbf{progressive}(\mathsf{verb})$
b $\mathbf{passive}(\mathsf{past} \wedge \mathsf{transitive})$

Most importantly from the perspective of the "atransformational" lexicon discussed in Section 2.1.1, we may isolate a subclass of possible statements of the form:

(108) $\mathbf{rule} = \langle \phi, \phi \wedge \psi \rangle$

that is, where the antecedent of the rule is contained in the consequent. Obviously, the import of such a rule is that its "output" is always a further specification of its "input". If we require all lexical rules to be of this form, we have constrained the lexicon to be atransformational—no properties of a lexical specification may

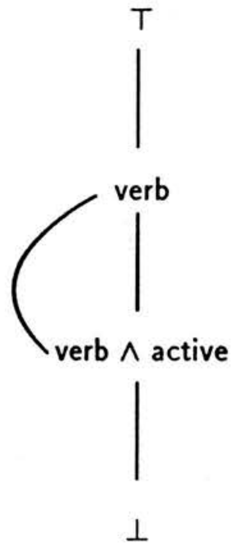

Figure 3–2: The non-defeating rule **Active** = $\langle \mathsf{verb}, \mathsf{verb} \wedge \mathsf{active} \rangle$

be defeated and derivation is simply the accretion of constraints. Equivalently, under this restriction, the following holds for all rules:

(109) $\phi \geq \mathbf{rule}(\phi)$

We may therefore characterize this kind of rule as *non-defeating*. A graphical representation of such a rule is shown in Figure 3–2, where the curved line represents the relation described by the rule.

A special case of non-defeating rules is of the form:

(110) $\langle \mathsf{true}, \phi \rangle$

where no properties are required to hold of the input to a lexical rule. In this case, we may reasonably identify this rule with ϕ, as the effect of such a rule is simply the conjunction of ϕ with the input specification. That is,

(111) $\mathbf{rule}(\psi) = \psi \wedge \phi$

Figure 3–3 illustrates this case.

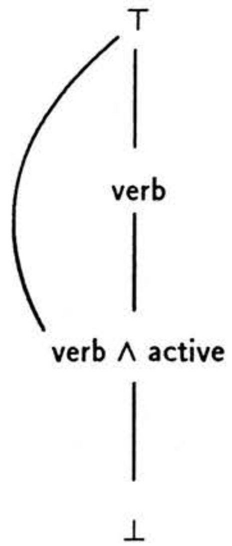

Figure 3–3: The non-defeating rule **Active** = ⟨true, verb ∧ active⟩

Rules which do not meet the requirement of (109) will be referred to as *defeating* rules. A graphical illustration is shown in Figure 3–4. Note that there is no element other than $\perp$ which is subsumed by both the antecedent and consequent of the rule. Of course, I have not so far given any indication of why it should be the case that the specification noun ∧ verb should be inconsistent. I will return to this question, and to this taxonomy of rules, in the discussion of *paradigmatic dimension*, in Section 3.3.4 below.

3.1.4 Paradigms

A *paradigm* is a triple, $\mathbf{p} = \langle\ \sigma : \phi,\ \langle \mathbf{r}_1, \ldots, \mathbf{r}_n \rangle,\ \langle \tau_1, \ldots, \tau_n \rangle \rangle$, $n \geq 1$. $\mathbf{p}$ is the unique name of the paradigm. The lexical specification of the paradigm plays an important role hereafter, hence,

(112) In a paradigm, $\mathbf{p} = \langle\ \sigma : \phi,\ \langle \ldots \rangle,\ \langle \ldots \rangle \rangle$, $\sigma : \phi$ is the *paradigmatic word.*

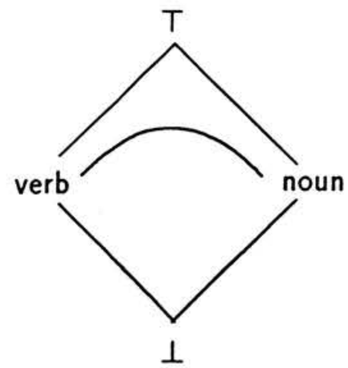

Figure 3–4: The defeating rule **Nominalization** = $\langle \mathsf{verb}, \mathsf{noun} \rangle$

The paradigmatic word is the underspecified word whose behaviour the paradigm describes.

In a paradigm such as $\mathbf{p}$, $\langle \mathbf{r}_1, \ldots, \mathbf{r}_n \rangle$ is a sequence of names of lexical rules. $\langle \tau_1, \ldots, \tau_n \rangle$ is a sequence of string specifications, with the restriction (to be reformulated slightly in Section 3.3) that any variables in τ_i also occur within σ, i.e. in the string specification of the paradigmatic word. τ_i is a *derived string form.* A description of English might require statements like the following in a paradigm:

(113) $\begin{array}{lll} \langle \ldots & \mathbf{past} & \ldots \rangle \\ \langle \ldots & x + \mathrm{ed} & \ldots \rangle \end{array}$

I will say that $\mathbf{p}$ *derives* string forms σ and τ_i via the lexical rule $\mathbf{r}_i$ under the conditions of paradigm $\mathbf{p}$. I will define the notion of *derivability via a paradigm* after first giving the definitions of *subsumption* over paradigms and *potential derivability via a paradigm.*

(114) A paradigm $\mathbf{p} = \langle\ \sigma : \phi, \ldots \rangle$ subsumes another $\mathbf{p}' = \langle \sigma' : \phi', \ldots \rangle$ iff $\sigma : \phi \geq \sigma' : \phi'$. I will write $\mathbf{p} \geq \mathbf{p}'$.

(115) A paradigm $\mathbf{p} = \langle\ \sigma : \phi, \ldots \rangle$ strictly subsumes another $\mathbf{p}' = \langle \sigma' : \phi', \ldots \rangle$ iff $\sigma : \phi > \sigma' : \phi'$. I will write $\mathbf{p} > \mathbf{p}'$.

I emphasize again at this point that the definition of subsumption over paradigms only takes into consideration the paradigmatic word. That is, the definition above ignores any information given by the paradigm concerning the possible lexical rules and string forms that the paradigm gives rise to. An implication of this is that it also makes sense to talk of subsumption relations between paradigms and lexical specifications. We may now turn to the use of paradigms in deriving lexical specifications. If we have a paradigm $\mathbf{p} = \langle\ \sigma : \phi,\ \langle \mathbf{r}_1, \ldots, \mathbf{r}_n \rangle,\ \langle \tau_1, \ldots, \tau_n \rangle \rangle$, and we unify its paradigmatic word with some lexical specification $\sigma' : \phi' \leq \sigma : \phi$ where σ' is ground, then by the requirement stated above, $\tau_1, \ldots, \tau_n$ will also be ground, according to the assignment of values to variables implied by the conjunction $\sigma \wedge_s \sigma'$. (As we are dealing with a system containing explicit variables, we have to make the proviso that variables occurring in lexical specifications and paradigms are appropriately renamed. Recalling the discussion of the interpretation of descriptions in terms of equivalence classes (Sections 2.3.2 and 2.3.4), this is unproblematic, as any description may be replaced by another member of its equivalence class so as to ensure that the variables mentioned in two descriptions are disjoint.)

(116) A lexical specification $\sigma : \phi$ *potentially derives* another $\tau : \psi$ via a paradigm $\mathbf{p} = \langle\ \sigma' : \phi',\ \langle \mathbf{r}_1, \ldots, \mathbf{r}_n \rangle,\ \langle \tau_1, \ldots, \tau_n \rangle \rangle$ iff $\sigma' : \phi' \geq \sigma : \phi$ and $\sigma' : \phi' \approx \sigma : \phi \rightarrow \exists i \tau_i = \tau$ and $\psi = \mathbf{r}_i(\phi)$.

As an example of this definition, consider the paradigm in (117a) and the lexical specification (117b).

(117) a $\mathbf{verb} = \langle s : \mathsf{verb} \wedge \mathsf{base}, \langle \ldots \mathbf{past} \ldots \rangle, \langle \ldots s + \mathrm{ed} \ldots \rangle \rangle$
      b think:$\mathsf{verb} \wedge \mathsf{base}$

(118) a $s \wedge_s \mathrm{think} \rightarrow s/\mathrm{think}$
      b $s \wedge_s \mathrm{think} \rightarrow s + \mathrm{ed} = \mathrm{thinked}$

Here the assignment of values to variables implied by (118a) means that the equation in (118b) also holds. So in this case, the paradigm **verb** potentially derives the specification

(119) thinked: $\mathbf{past}(\mathsf{verb} \wedge \mathsf{base})$

That a paradigm potentially derives some specification is not sufficient for it actually to do so, due to the following condition:

(120) A paradigm $\mathbf{p}$ *derives* $\tau : \psi$ from the lexical specification $\sigma : \phi$ iff $\mathbf{p}$ potentially derives $\tau : \psi$ and there is no paradigm $\mathbf{p}'$ such that $\mathbf{p} > \mathbf{p}'$ and $\mathbf{p}' \geq \sigma : \phi$. I will write $(\mathbf{p}, \sigma : \phi) \Rightarrow \tau : \psi$.

(A qualification to this definition is made in (156).) (116) requires that the lexical specification of the paradigm subsume the lexical item in question. (120) requires that there be no paradigm whose lexical specification is strictly more specific than that of **p** which is also applicable to the lexical item. The effect of (120) is to enforce a generalized Elsewhere Condition (see Section 2.4.1), under which a morphological operation is only allowed if there is no more specific statement which also holds. If there is a more specific paradigm which by (120) prevents a more general paradigm from being used in a derivation, I will speak of the more specific *pre-empting* the more general. It is also important to note that, if there are two paradigms of equal specificity, both may be used to derive further lexical specifications. This is the result of definition (120) in terms of strict subsumption—if we had opted for the nonstrict definition of subsumption, no derivation would be allowed in the case of two equally specific paradigms.

Some discussion is required here of the fact that I have not made any requirement that a more specific paradigm, in pre-empting a more general one, actually derives some lexical item or that such a lexical item is related in some way to the lexical specification that would be generated by the more general paradigm in the absence of the more specific. This aspect of the definition is motivated by the discussion in Section 2.4.1. There, we saw that using some version of the Elsewhere Condition in determining the applicability of some statement may require us to define some kind of measure of similarity between the outputs of rules governed by the EC. My proposal amounts to the statement that, for a paradigm of a given specificity, all "relevant" outputs are given. The notion "relevant" will be discussed in Section 3.3.4. One of the unfortunate consequences of this proposal, namely that information may be redundantly repeated across paradigms, is addressed in Section 3.3. Having defined the concepts of lexical specifications, lexical rules and paradigms, I now offer the following definition of a *paradigmatic grammar*.

A *paradigmatic lexicon* L is a 7-tuple $\langle N, C, V, W, R, P, \Pi \rangle$, and the following conditions hold. N consists of a set of names {**passive, strong verb, ...**}, and a naming relation which assigns a unique name to elements of Π and R. C and V are as before, W, the *base lexicon*, is a set of lexical entries, R is a set of lexical rules, P is a set of morphosyntactic properties {active, base ...} and Π is a set of paradigms.

The provision of names for paradigms and lexical rules is not strictly necessary at this level of abstraction. In the case of lexical rules, this provision will be useful in the definition of *composite* lexical rules, Section 3.3.4 below.

We are now in a position to define the set of lexical items described by a paradigmatic lexicon. I will offer two formulations. The first of these I will term the *inclusive* closure of the lexicon, as the definition results in the set of lexical entries defined in the base lexicon being included within the set of lexical items derivable from it. The second I will term *exclusive*, as it allows for the situation in which the set of lexical entries is not included in the derived set of lexical items.

Given a lexicon $L = \langle N, C, V, W, R, P, \Pi \rangle$ as above, the set of lexical items is defined as the closure of the lexicon under the application of lexical rules mediated by the paradigms. First, the definition of inclusive closure under derivability ($\stackrel{*}{\Rightarrow}_i$) is

(121) $L \stackrel{*}{\Rightarrow}_i \sigma : \phi$
a if $\sigma : \phi \in W$ or
b if $L \stackrel{*}{\Rightarrow} \sigma' : \phi'$ and, for some $\mathbf{p} \in \Pi$, $(\mathbf{p}, \sigma' : \phi') \Rightarrow \sigma : \phi$

Exclusive closure under derivability differs by excluding non-derived forms:

(122) $L \stackrel{*}{\Rightarrow}_e \sigma : \phi$ if for some $\mathbf{p} \in \Pi$
a $(\mathbf{p}, \tau : \psi) \Rightarrow \sigma : \phi$ and $\tau : \psi \in W$ or
b $(\mathbf{p}, \tau : \psi) \Rightarrow \sigma : \phi$ and $L \stackrel{*}{\Rightarrow}_e \tau : \psi$.

(123) The set $\mathcal{W}$ of derived lexical items is then $\{w | L \stackrel{*}{\Rightarrow} w\}$.

where this definition may be further specified as "inclusive" or "exclusive". In what follows, I shall assume that the exclusive definition is in force.

There are two points to note about the definitions given above. First, nothing in the formalism I propose constrains the set of lexical items to be finite. Second, the restrictions we have imposed on lexical entries and variables in derived strings imply that, in the lexical items that result from the application of paradigms, there will be no string variables.

I end this set of definitions with that of *exemplary paradigm* (see Section 2.1.2 above). The exemplary paradigm associated with a lexical entry is the set of lexical items that it gives rise to. We may characterize this simply enough by restricting the base lexicon W to the lexical entry of interest. That is,

(124) If $L = \langle N, C, V, W, R, P, \Pi \rangle$ is a paradigmatic lexicon and $w \in W$, then the exemplary paradigm of w is the set of items derivable from $\langle N, C, V, \{w\}, R, P, \Pi \rangle$. I will write **exemplary**(L, w).

I now illustrate the use of the definitions given above.

3.2 Example Paradigms and Lexical Rules

Shown below are example paradigms from a possible description of English. To aid legibility, I will represent the components of a paradigm in the following way:

(125) **Paradigm Name**
Paradigmatic word

Lexical Rule$_1$	*derived string form*$_1$
Lexical Rule$_2$	*derived string form*$_2$
...	...
Lexical Rule$_n$	*derived string form*$_n$

The subsumption relations engendered by these paradigms are shown in Figure 3–5, where the elements $\top$, the paradigm with no specification, and $\perp$, the paradigm with an inconsistent specification, have been added to complete the lattice.

(126) **verb**

s:verb ∧ base

base	*s*
3sg	*s*+s
non3sg	*s*
past participle	*s*+ed
past	*s*+ed
passive	*s*+ed
progressive	*s*+ing

(127) **verb in e**

s+e:verb ∧ base

base	*s*+e
3sg	*s*+es
non3sg	*s*+e
past participle	*s*+ed
past	*s*+ed
passive	*s*+ed
progressive	*s*+ing

(128) **verb strong**

s+in+g:verb ∧ strong ∧ base

base	*s*+in+g
3sg	*s*+in+g+s
non3sg	*s*+in+g
past participle	*s*+un+g
past	*s*+an+g
passive	*s*+un+g
progressive	*s*+in+g+ing

(129) **verb age**

age:verb ∧ base

base	age
3sg	age+s
non3sg	age
past participle	age+d
past	age+d
passive	age+d
progressive	age+ing

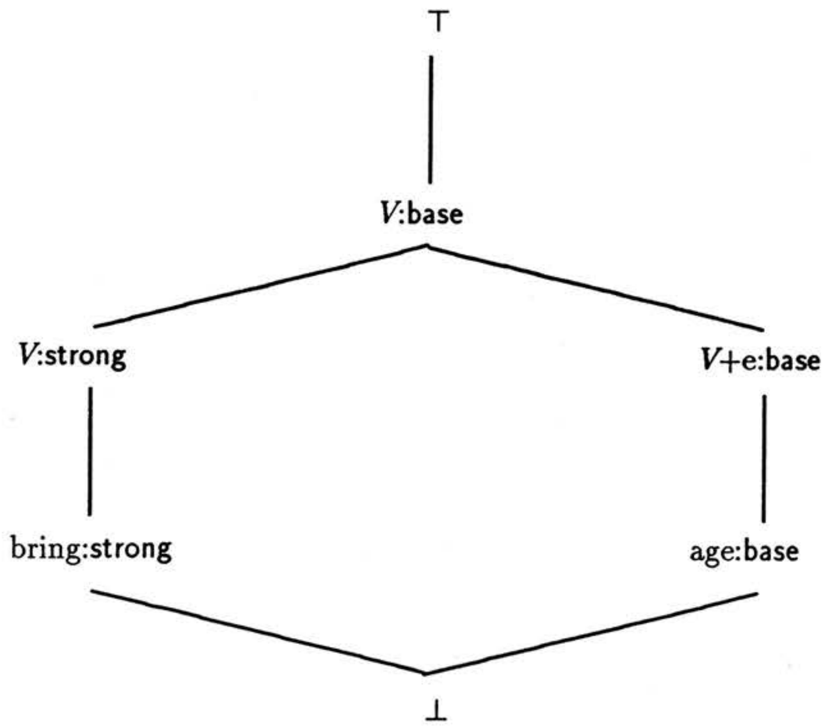

Figure 3–5: Subsumption Relations between the paradigms of (126) to (130)

(130) **verb bring**

bring:verb ∧ strong ∧ base

base	bring
3sg	bring+s
non3sg	bring
past participle	brought
past	brought
passive	brought
progressive	bring+ing

Lexical rules which might be used with these paradigms are:

(131) a **base** = ⟨true, true⟩
b **3sg** = ⟨base, finite ∧ 3sg⟩
c **non3sg** = ⟨base, finite ∧ non3sg⟩
d **past participle** = ⟨base, participle ∧ past⟩
e **past** = ⟨base, finite ∧ past⟩
f **passive** = ⟨base, participle ∧ passive⟩
g **progressive** = ⟨base, participle ∧ present⟩

The following lexical items may be used in conjunction with the paradigms in (126) to (128):

(132) a walk:verb ∧ base
b wave:verb ∧ base
c ring:verb ∧ base ∧ strong
d ring:verb ∧ base
e age:verb ∧ base
f bring:verb ∧ base ∧ strong

3.2.1 Example Derivations

Consider the two lexical items with the form *ring* above. These differ only in that one has the morphosyntactic specification strong while the other does not. This difference leads to two different derivations. In the case of (132d), as in *the birds are ringed each summer*, there is only one paradigm which potentially derives any forms. That is, apart from the paradigm in (126), there is no paradigm which subsumes (132d). In this case the condition in (120) is met, and we may use the paradigm (126) to derive further forms.

As stated in the definition (116), a string form may be derived on the basis of the unification of a lexical specification with the paradigmatic word. In this case,

(133) (s:verb ∧ base) ∧ (ring:verb ∧ base)

which is just (132d), and yields the unifier:

(134) $\{s/\text{ring}\}$

Applying this unifier to the string specification s+ed yields the string "ringed", and so we are allowed to infer that this string is the form that results under application of the lexical rule **passive**. The lexical item that results is then:

(135) ringed:verb ∧ passive ∧ participle

On the other hand, the lexical specification in (132c) is subsumed by two paradigms, (126) and (128). Of these, the former is more general and so, by (120), it may not be used to derive specifications from (132c). We may however use the paradigm (128). Here, the unification of paradigmatic word and lexical specification is just (132c). The unifier it yields is:

(136) $\{s/\mathrm{r}\}$

which, applied to the string specification s+un+g, yields the string "rung". The form that corresponds to the application of **passive** is then

(137) rung:verb ∧ passive ∧ participle ∧ strong

Note that neither of the derived forms gives rise to further derivations, as neither carries the specification base.

Finally, the exemplary paradigm of (132c) is the set:

(138) { ring:verb ∧ base,
ring:verb ∧ non3sg,
rings:verb ∧ 3sg,
rung:verb ∧ past ∧ participle,
rang:verb ∧ past ∧ finite,
rung:verb ∧ passive ∧ participle,
ringing:verb ∧ present ∧ participle}

3.3 Further Mechanisms

Clearly the paradigms given above suffer from the verbosity standardly attributed to paradigmatic descriptions. I now present four mechanisms which allow descriptions to be more concise or extend our range of descriptive devices. In all but one case, these mechanisms may be realized in terms of the apparatus introduced above. The first three mechanisms, namely additional operations over strings, character classes and functional and relational dependencies, allow the more succinct expression of orthographic information, while the fourth allows the omission of statements when they may be inferred from other paradigms. All of these proposals are concretely exemplified in Appendix A.

Additional constraints on strings

The paradigms shown in (126) to (130) do not allow the analysis and construction of strings other than through the structurally given positions of paradigmatic word and resulting string forms. Thus, in the above examples, we are forced to construct the same form at least twice to represent the past participle and passive forms. To avoid this repetition, we allow the use of conjunctions of strings, stated with the properties of a paradigm, to construct particular forms, resulting in statements such as (139)

(139) $\sigma : \phi$ where $\sigma \wedge_s s + \mathrm{k}, past \wedge_s s + \mathrm{g}$

which says that σ is a string ending in the character "k" and the new string *past* is defined to be just like σ except that *past* ends in "g". Paradigm (126) might then be stated as:

(140) **verb**

s:verb $\wedge$ base where *past* $\wedge_s$ s+ed

base	s
3sg	s+s
non3sg	s
past participle	*past*
past	*past*
passive	*past*
progressive	s+ing

In the analysis of Latin below, the paradigm shown in A-11 makes further use of this device.

If such constraints may be seen to correspond to a finite set of conjunctively specified paradigms, as all examples in this thesis will be, it is perhaps easiest to view this device as an abbreviatory convenience. That is, any qualifications expressed in the above way could be equivalently expressed in terms of annotations of the paradigmatic word.

As discussed in Section 2.3.4, there are advantages to keeping within the class of string operations defined as $P_{0.5}$. In the context of multiple conjunctions describing strings, I have to provide the following ancillary definitions. A set of conjunctions over strings is in $P_{0.5}$ if there is some ordering over the set such that, in sequence, the conjunctions are individually in $P_{0.5}$. In other words, the assignment of values to variables implied by earlier conjunctions are sufficient to place later equations in $P_{0.5}$. So an example of a $P_{0.5}$ set is shown in (141), since in the order shown below, each conjunction is $P_{0.5}$. By contrast, the set in (142) is not $P_{0.5}$:

(141) $\mathrm{a}+x \wedge_s \mathrm{abc}$
$y+y \wedge_s x+x$
$x+\mathrm{a} \wedge_s z+x+\mathrm{a}$

(142) $x+\mathrm{y}+x+y \wedge_s z+\mathrm{yab}+z$
$u+\mathrm{yab}+z \wedge_s z+u$
$x+x \wedge_s t+t$

The formalism we have developed above for describing strings is purely conjunctive. It is, of course, entirely open to us to extend the formalism we have developed to allow the expression of negative and disjunctive information (although we cannot guarantee that desirable computational properties continue to hold).

(143) a $s \wedge_s \neg \mathrm{d}$
b $s \wedge_s (\mathrm{g} \vee \mathrm{ng})$

where the first describes strings which are distinct from "d", and the second strings consisting of either the character "g" or the string "ng". That is, we impose the same kind of algebraic structure on string descriptions that we find in morphosyntactic descriptions. The addition of negation to a system for string description is, in fact, essential, if we wish the theory transformation discussed in Section 2.4.1 and 4.2.1 below to be workable. On the other hand, if the constraints so expressed correspond to a finitely enumerable set of conjunctive descriptions, we may, as discussed above, interpret such statements as purely abbreviatory.

Character Classes

As phonological properties associated with orthographic elements often determine the form presented by a particular word, it makes sense, as a generalization of the mechanisms described above, to allow the separate statement of those characters which fall into particular phonological classes, such as the class of vowels. A case in point is (128) which is more specific than it need be, because that paradigm is restricted to forms ending in "ng", whereas this pattern of inflection is also found with verbs such as *drink*. A *character class* is then defined as a subset of the set of characters, cf. Karttunen *et al* (1987, p17). I will use the following syntax for the expression of classes:

(144) **Velar** $= \mathrm{g} \vee \mathrm{k}$

and so **Velar** $\wedge_s x$ will describe any string described by either "g" or "k" (see also (209) in Appendix A).

Karttunen *et al* (1987) point out that the notion of character classes may be generalized to that of *definitions*. A definition is, in their formalism, a regular expression over the alphabets defined in a two-level morphology system and the character classes defined as above. Thus they allow (Karttunen *et al* 1987, p18) the following definition for "Syllable":

(145) Syllable = C* V (V) C*

where C is defined elsewhere to be the set of consonant symbols, and V the set of vowel symbols. That is, a syllable consists of some possibly empty sequence with elements drawn from C, followed by one or two elements from V and another possibly empty sequence from C. In the system I propose here, much the same device is available, except that constructions from regular languages such as the Kleene star are not expressible in the formalism developed so far; there is no means to state that a string consists of an arbitrary number of occurrences of the character "a", i.e. the regular expression "a*".[1] The only means at our disposal for talking about strings which contain an arbitrary number of repetitions of some elements is either to mention individual occurrences or to produce an infinite string using the "pathological" description, as in 2.(46). An approximation to the above example above could then be rendered as:

(146) **Syllable** $= (c_1 \vee \varepsilon) + (c_2 \vee \varepsilon) + (c_3 \vee \varepsilon) + v_1 + (v_2 \vee \varepsilon) + (c_4 \vee \varepsilon) + (c_5 \vee \varepsilon) + (c_6 \vee \varepsilon) + (c_7 \vee \varepsilon)$ where **Consonant**(c_i) and **Vowel**(v_j).

(The use of the empty string here is not essential).

Functional and Relational Dependencies

A relational dependency between characters of the alphabet is a subset R of $C* \times C*$, where $C*$ is the monoid of C. A functional dependency is a relation F such that, if $\langle \sigma_i, \sigma_j \rangle$ and $\langle \sigma_i, \sigma_k \rangle \in F$, then $\sigma_j = \sigma_k$. (Doug Jones (in

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[1] The addition of regular language devices to a system using string unification is discussed by Bird (1990). Work by Schulz (1990, Ch. 7) suggests that this does not lead to technical problems.

Calder *et al* 1989) has also pointed out the possibility of using relations, in his case stated as rewrite rules, in this way). Thus a function **voiced** which relates characters to their voiced counterparts could be defined as:

(147) $$\textbf{voiced} = \{ \begin{array}{l} \langle \text{t} \quad \text{d} \rangle \\ \langle \text{d} \quad \text{d} \rangle \\ \langle \text{s} \quad \text{z} \rangle \\ \langle \text{z} \quad \text{z} \rangle \\ \langle \text{a} \quad \text{a} \rangle \\ \dots \quad \} \end{array}$$

In order to represent the constraints on strings introduced here, I will allow the following annotation of the paradigmatic word:

(148) $\sigma : \phi$ where $\sigma \wedge_s x + c, \textbf{consonant}(c), \textbf{voiced}(c) \wedge_s \text{t}$

If a variable, such as x in this case, is used as a term in a relation, it is therefore constrained to fall within the sets picked out by that relation. If the paradigmatic word is thereby constrained, this has to be taken into account in determining the subsumption relations between the paradigm in question and others. Use of this kind of expression is made in (159) and A–12 below. I assume, here and in the appendix, that functions and relations are finitely enumerated. Relaxing this restriction would offer a way of encoding regular language expressions.

Formally, we may extend the definition of a paradigmatic lexicon, replacing C with $\langle C, K \rangle$, where C is as before and K is a set of specifications of character classes and dependencies.

A Default Mechanism

The third mechanism is considerably more complex and effects a rapprochement between my scheme and those of default logics for lexical description (Gazdar and Evans 1989a,b) and object-oriented morphophonemics (Daelemans 1988). To start with, we require a definition of *directly subsuming* paradigm.

(149) A paradigm $\mathbf{p}$ *directly subsumes* another $\mathbf{p}'$ if $\mathbf{p} > \mathbf{p}'$ and $\mathbf{p} \geq \mathbf{p}'' \geq \mathbf{p}' \rightarrow \mathbf{p} = \mathbf{p}'' \vee \mathbf{p}'' = \mathbf{p}'$.

That is, there is no paradigm that lies between $\mathbf{p}$ and $\mathbf{p}'$. Also the fact that a paradigm makes reference to a particular lexical rule needs a formal definition:

(150) A paradigm $\mathbf{p}$ *references* a lexical rule $\mathbf{r}$ iff $\mathbf{p} = \langle \sigma : \phi, \langle \mathbf{r}_1, \ldots, \mathbf{r}_n \rangle, \langle \tau_1, \ldots, \tau_n \rangle\rangle$ and $\mathbf{r} = \mathbf{r}_i$, for some i, $1 \leq i \leq n$.

The following definition then allows us to abbreviate paradigms in the case when a less specific paradigm contains essentially the same information:

(151) Given a paradigm $\mathbf{p} = \langle \sigma : \phi, \langle \mathbf{r}_1, \ldots, \mathbf{r}_n \rangle, \langle \tau_1, \ldots, \tau_n \rangle\rangle$, if there is only one directly subsuming paradigm $\mathbf{p}' = \langle \sigma' : \phi', \langle \mathbf{r}'_1, \ldots, \mathbf{r}'_m \rangle, \langle \tau'_1, \ldots, \tau'_m \rangle\rangle$, and for some i, $\mathbf{r}_i = \mathbf{r}'_i$ and $\sigma' \wedge_s \sigma \rightarrow \tau_i = \tau'_i$, references to $\mathbf{r}_i$ and τ_i in $\mathbf{p}$ may be omitted from $\mathbf{p}$.

In other words, we allow the inheritance of a string form and associated lexical rule from the more general paradigm if we would get the same result using either $\mathbf{p}$ or $\mathbf{p}'$. In the case of n directly subsuming paradigms, the same convention applies if the following condition is met:

(152) $\sigma \wedge_s \sigma_1 \ldots \wedge_s \sigma_n \rightarrow \tau_i = \tau'_{i,1} \ldots = \tau'_{i,n}$.

That is, multiple inheritance must be consistent.

To complete this proposal, I now add a further condition to the definition of derivability given in (120). Effectively, this will allow us to "undo" the effect of the abbreviatory mechanism defined above. A paradigm may inherit a lexical rule as follows:

(153) Let $\mathbf{p}$ and $\mathbf{p}'$ be two paradigms such that $\mathbf{p}' > \mathbf{p}$ and, for some lexical rule $\mathbf{r}$, $\mathbf{p}'$ references $\mathbf{r}$ while $\mathbf{p}$ does not reference $\mathbf{r}$. If there is no paradigm $\mathbf{p}''$, $\mathbf{p}' > \mathbf{p}'' > \mathbf{p}$ which references $\mathbf{r}$, then $\mathbf{p}$ *inherits* $\mathbf{r}$ from $\mathbf{p}'$.

(154) If $\mathbf{p}$ inherits $\mathbf{r}$ from $\mathbf{p}'$, $\mathbf{p} = \langle \sigma : \phi, \langle \mathbf{r}_1, \ldots, \mathbf{r}_n \rangle, \langle \tau_1, \ldots, \tau_n \rangle\rangle$ and $\mathbf{p}' = \langle \sigma' : \phi', \langle \mathbf{r}'_1, \ldots, \mathbf{r}, \ldots \mathbf{r}'_m \rangle, \langle \tau'_1, \ldots, \tau, \ldots, \tau'_m \rangle\rangle$, then the *expanded* form of $\mathbf{p}$ is:
$\exp(\mathbf{p}) = \langle \sigma : \phi, \langle \mathbf{r}_1, \ldots, \mathbf{r}_n, \mathbf{r} \rangle, \langle \tau_1, \ldots, \tau_n, \tau \rangle\rangle$

(155) A paradigm $\mathbf{p}$ is in its *maximally expanded form* if there is no rule it may inherit from another paradigm.

The definition of derivation in (116) and (120) must now be revised, qualifying "paradigm" with "maximally expanded paradigm".

(156) $(\mathbf{p}, \sigma : \phi) \Rightarrow \tau : \psi$ as in (120) only if **p** is in its maximally expanded form.

The notion of inheritance developed here may be contrasted with that used in DATR (Evans and Gazdar 1990). In the latter case as seen in Section 2.4.4, inheritance is explicitly marked by means of an equation between node-path specifications, whereas here inheritance is implicit—we have to examine the paradigmatic words of two paradigms and the lexical rules they reference in order to determine whether an inheritance relation holds. One of the effects of this is that, for an inheritance relation to hold, we are forced into the position of repeating the information in virtue of which the Elsewhere Condition is applicable. That is, if we have paradigms **p** and $\mathbf{p}'$ such that $\mathbf{p} \geq \mathbf{p}'$, we have necessarily repeated in $\mathbf{p}'$ the definition of the paradigmatic word of **p**. This problem aside, the notion of inheritance here may be likened to local inheritance in DATR.

One issue that arises as the result of introducing inheritance between paradigms is that of lexical entries which are *defective*, as, for example in the case of the French verb *clore* "close", which has no imperfect or *passé simple* forms; if we are allowed to derive a specification by means of a more general paradigm than would be the case in the absence of (151), the situation where a particular lexical rule is not mentioned because a more general rule applies is confused with that in which it is not mentioned because that form should not be allowed by the grammar. A solution to this problem is discussed in Section 3.3.4. Further exemplification of this default mechanism is given in Appendix A. In particular, the reader might like to compare the information in A-1, with that in A-10.

3.3.1 Abbreviated Paradigms

With the mechanisms described above, we may now represent the paradigms given in (126) to (130) as follows:

(157) **verb**

s:verb ∧ base

base	s
3sg	s+s
non3sg	s
past participle	s+ed
past	s+ed
progressive	s+ing

(158) **verb in e**

s+e:verb ∧ base

3sg	s+es
past participle	s+ed
past	s+ed
progressive	s+ing

(159) **verb strong**

s+in+k: verb ∧ strong ∧ base where **Velar(k)**

past participle	s+un+k
past	s+an+k

(160) **verb age**

age:verb ∧ base

progressive	ageing

(161) **verb strong**

bring:verb ∧ strong ∧ base

past participle	brought
past	brought

(162) **passive**

s:participle ∧ past

passive s

In the above example, we have also taken advantage of the definition of the set of lexical entries as the closure of the lexicon under derivability via the paradigms. This allows us to factor out the information about passive forms and their string identity with past participle forms into a single, general statement. More specifically, we may read (162) as "the passive form of a verb is derived from that of the past participle". In this case, we have to change the definition of (131f) to be:

(163) **passive** = ⟨participle ∧ past, participle ∧ passive⟩

In other words, parasitic or Priscianic derivations (Matthews 1972, p169, and Section 2.1.2 above) are allowed within this system. The following section discusses the possible disadvantages of such an approach.

3.3.2 "Subsidiary" paradigms

In the small analysis of English verbal morphology presented above, I allowed the derivation of a lexical item from some other derived lexical item. That is, the fact that there is *syncretism* (Matthews 1974, p11) between forms corresponding to different lexical rules is factored out of the individual paradigms and set up as a rule which applies to derived forms. I shall term paradigms which make reference to derived forms *subsidiary* paradigms. Such proposals have often been viewed with suspicion within linguistics, and we may identify the following reasons for concern. First, such an analysis may appear to imply that the computation of the passive form of a word proceeds necessarily via the computation of the past participle form. Second, the choice of the 'intermediate' form may be somewhat arbitrary. These concerns are raised by Matthews (1972, p29), although he and other authors (e.g. Starosta 1988, Anderson 1988a, p186) are willing to make use of such descriptive devices. (Matthews (1965a, p164) says: "the reader may not like this expedient, but he will agree that some generalization is required"). As I have resorted to this expedient, I have therefore to ask to what extent these concerns are well-founded.

The first criticism may be likened to Pullum's (1976) "Duke of York" derivations in phonology—in the process of derivation, we are doing work that will have to be undone at some later point. In (157), (162) and (163), we appear to introduce the specification past only to replace it with the specification passive. A response to this is to say that the use of subsidiary paradigms in the case mentioned (and in those used in Section A.2.1 below) can be seen as purely abbreviatory—they allow us to factor out regularity, thereby allowing a more compact representation of the paradigms in question. The formal basis of this abbreviation may be explicated by analogy to the use of *metarules* in GPSG (Gazdar *et al* 1985, Ch. 4). In that theory, in addition to the statements that define a basic set of phrase structure rules, metarules provide ways of defining other phrase structure rules on the basis of the first set. For example, the *Complement Omission Metarule* (Gazdar *et al* 1985, p. 124) is stated as follows:

(164)

$$\begin{array}{c}[+\mathrm{N},\ \mathrm{BAR}\ 1] \rightarrow \mathrm{H},\ W \\ \Downarrow \\ [+\mathrm{N},\ \mathrm{BAR}\ 1] \rightarrow \mathrm{H}\end{array}$$

which we may gloss as "to any rule which expands an adjective or noun (i.e. +N) at bar level one as the head daughter and some complement (i.e. W), there corresponds another rule just like the first except that the complement does not appear".

Now, the grammar that corresponds to a GPSG involving metarules will contain some set of phrase structure rules some of which were derived by metarule from the more basic set. However, there is nothing in the derived rules that indicates their history or in any other way sets them apart from other rules—the analysis of a sentence involving a rule derived by metarule need not proceed by determining the structure corresponding to the non-derived rule and thereafter transforming it as determined by the metarule.

The same interpretation, with some qualifications, is open to us in the case of subsidiary paradigms; we may view a subsidiary paradigm as simply a way of abbreviating other paradigms. In effect, we can consider a "most general derivation" from a paradigm. If a paradigm with paradigmatic word $\sigma : \phi$ derives a string form τ under rule $\mathbf{r}$, the most general derivation is simply $\tau : \mathbf{r}(\phi)$. (This will be defined if application of the rule $\mathbf{r}$ to ϕ is defined, i.e. if application is not dependent on some property given lexically, over and above the properties stated with the paradigmatic word.)

If the paradigmatic word $\tau' : \psi'$ of some paradigm **p** subsumes a most general derived form $\tau : \psi$ from some other paradigm **p**$'$ with paradigmatic word $\sigma : \phi$ then we may extend the definition of **p**$'$ as in (154) with a specification by means of which **p**$'$ directly derives the forms that **p** derives. If the lexical rules used by a pair of paradigms to perform a parasitic derivation are **r** and **s**, so that the result of derivation is $\mathbf{s}(\mathbf{r}(\phi))$ for some ϕ, the lexical rule that is used to expand the paradigm is then the composition of the rules **r** and **s**. Consider the schematic paradigms in (165), expressing the situation described above, i.e. where $\tau' : \psi' \geq \tau : \mathbf{r}(\phi)$:

(165) a **p**
$\sigma : \phi$
$\ldots \mathbf{r} \ldots$
$\ldots \tau \ldots$
b **p**$'$
$\tau' : \psi'$
$\ldots \mathbf{s} \ldots$
$\ldots \sigma' \ldots$

We may then extend the definition of **p** to

(166) **p**
$\sigma : \phi$ where $\tau \wedge_s \tau'$
$\ldots \mathbf{r} \ldots \mathbf{s;r}$
$\ldots \tau \ldots \sigma'$

This more explicit formulation suggests two provisos that should be made, in order for this transformation not to alter possible derivations. The first is that the conjunction $\tau \wedge_s \tau'$ should not impose any further constraints on the paradigmatic word $\sigma : \phi$. The second is that the composite rule **s;r** on ϕ should be equivalent to $\mathbf{s}(\mathbf{r}(\phi))$, i.e. there are no possible orderings of subrules from **s** and **r** which give rise to distinct descriptions. Uses of subsidiary paradigms may then be seen to fall under the schematic diagram shown in Figure 3–6.

The second criticism of parasitic derivations, that the choice of form to be used as a basis for other derivations is arbitrary, is less easily met. In the situations in which metarules are used by Gazdar *et al* (1985, p249), it is easy to make the case that derivation should proceed in a particular direction. In the case of the Passive

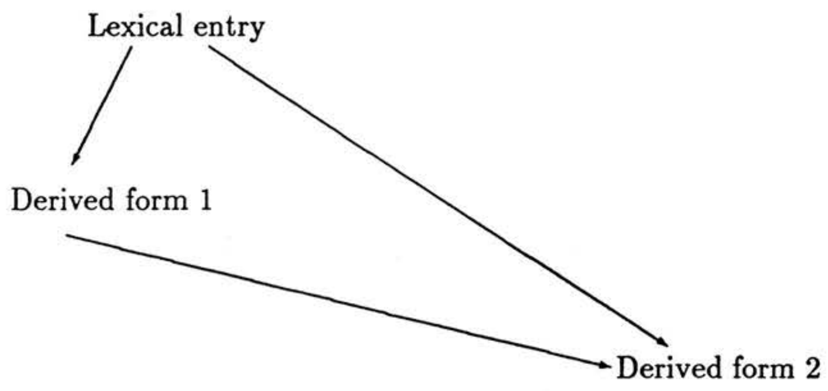

Figure 3–6: The relations between lexical entries and forms derived by subsidiary paradigms

and Slash Termination Metarules (*STM*1 and 2), syntactic categories mentioned in the metarules bear feature specifications which violate defaults stated elsewhere in the grammar. From a purely grammar-internal point of view then, the situations allowed by metarule are in some sense abnormal. It is much more difficult to make the case that some form, say the active imperfect indicative first person singular, has some privileged status with respect to other forms, say the corresponding second person plural, and it therefore represents an inappropriate generalization (cf. Matthews 1972, p29, for this use of "appropriate"). In the analysis of Latin in Appendix A below, such arbitrariness will be seen (and is here apologized for). Some comments as to how this problem might be addressed are also made.

3.3.3 Principal parts

A standard technique in traditional grammars for the description of the morphological behaviour of a particular lexical entry is to state its *principal parts.* (Matthews (1972, p10) uses the term *leading forms*). That is, some set of forms indicates which pattern of declension or conjugation the entry follows. For instance, Clendon and Vince (1932) give the following principal parts for the verb *possidēre*, "to possess":

(167)	*Present*	*Infinitive*	*Perfect*	*Supine*
	possideō	-ēre	possēdī	possessum

From this information it is possible to determine that the appropriate paradigm is to be found as the Second Conjugation. Within the linguistics literature, similar proposals to allow a more complex specification of the orthographic forms of items may be found in Starosta (1988) and Pollard and Sag (1987, Ch. 8) *inter alia*. Only the latter source goes into any detail about how such information may be represented. We may view such proposals as conflating two different kinds of information. On the one hand the specification of an irregular form not only marks the fact that a particular item evidences irregularity, but also gives an indication as to the actual form of the irregularity. That is, the information is both diacritic and substantive.

Within the setting developed above, the concept of principal parts is easy to introduce. We are however faced with a technical choice. We might choose to define principal parts as tuples of strings. That is, in place of a single string specifications associated with the paradigmatic word, we allow multiple specifications. This requires us to define the relation of subsumption over multiple specifications. The following is one possible formulation:

(168) $\langle s_1 \ldots s_i \rangle$ subsumes $\langle t_1 \ldots t_i, t_{i+1} \ldots t_j \rangle$ iff $j \geq i$ and there exists a unifier θ such that $\forall n (1 \leq n \leq i)\ \theta(s_n) = t_n$.

This statement would allow any tuple of principal parts to subsume another if each of the elements of the first subsumes the corresponding element of the second. However this formulation is problematic in the case where it is inconvenient to presuppose a constant ordering of the principal parts, a situation that would arise in a language where items showed differing degrees of irregularity in different parts of the paradigm. In other words, if a paradigm described irregularity in some strings related to principal part s_i, we would expect there to be irregularity in all strings related to s_j for $j < i$.

Another possible formulation, similar to that proposed by Pollard and Sag (1987, Ch. 8), would be to allow the specification of principal parts in a way which did not imply such dependencies between irregular forms. Assuming there is some upper bound on the number of principal parts, say n, we may assume some arbitrary ordering over principal parts and a set of "selectors" which refer to some particular element in the set of principal parts. If, for example, we decided on the need for four specifications corresponding to the principal parts given in (167), we might associate these with some structure such as:

(169) $\langle s_1, s_2, s_3, s_4 \rangle$

and allow the use of a selector to refer to some position within this structure. So, we can by convention identify the string given as part of the paradigmatic word with, say, s_2, **Present** with s_1, **Perfect** with s_3 and **Supine** with s_4. The paradigmatic word plays in this case a role analogous to the "citation form" of a word. If we allow the association of such specifications with the morphosyntactic properties of paradigmatic word, then the specifications in (170) would give rise to the sequences of principal parts shown in (171).

(170) a x+ēre: verb where **Present**(x+eō), **Perfect**(x+ēdī) and **Supine**(x+essum)

b x+ēre: verb where **Supine**(x+essum)

c x+ngere: verb where **Supine**(x+ctum), **Past**(x+gi)

(171) a ⟨x+eō, x+ēre, x+ēdī, x+essum⟩

b ⟨w, x+ēre, y, x+essum⟩

c ⟨w, x+ngere, x+ctum, x+gi⟩

There is a potential difficulty with both of these suggestions, which is brought out more clearly by the first. If we allow specifications of principal parts in the paradigms which we assume to generate lexical items "in one step" from lexical entries, their paradigmatic words will represent a different kind of mathematical object to those associated with subsidiary paradigms, as discussed in Section 3.3.2 and used in the description of Latin offered below (Section A.2.1). That is, if we assume the lexical representation of orthographic information contains more than just a single string, paradigms which derive forms from lexical entries will have to have a form which is compatible with this kind of representation. On the other hand relations between derived string forms are stated over particular single orthographic forms. That is, we may have to change our interpretation of derivability to take account of this problem. One way of doing this would be to say that subsidiary paradigms give rise to the same kind of structure of principal parts and so the orthographic specification of the paradigmatic word represents in some sense the "current" state of the derivation. There is a consequence of this proposal which is possibly undesirable from a linguistic point of view, namely that subsidiary paradigms may make reference to the orthographic representations that are given lexically, rather than to the derived orthographic representation, thereby allowing "global" constraints on derivations. This possibility is not discussed by the sources referenced in this section, but does not appear to be ruled out by any of them.

3.3.4 Paradigmatic Dimension

Morphological Oppositions

The system presented so far has contained the implicit assumption that paradigms can be usefully represented as one-dimensional objects—the paradigms above give information along a single axis defined by lexical rules. This assumption goes hand-in-hand with our previous assumptions about the nature of relations between lexical items. If they can be expressed only in terms of a single morphosyntactic operation (that is, a single lexical rule) then a one-dimensional structure is arguably the most appropriate.

While this assumption does not cause any formal problems, it fails to capture the intuition that there is more structure to the possible relations that lexical items enter into. In other words, we cannot refer, say, to the active (part of the) paradigm of some lexical entry, without additional information stating which lexical rules give rise to that part of the paradigm. Since part of Matthews' (1965b) programme, as discussed in Section 2.1.2, is to examine the notion of paradigmatic dimension, let us now consider how his proposals may be integrated with the system described so far.

Our first task is to reconstruct the notion of "morphological opposition". To do this we need to be able to state for a morphosyntactic category (in Matthews' sense of category, Section 2.1.2) those morphosyntactic properties which are exponents of that category. Thus, we might say that the properties active and passive are mutually exclusive exponents of VOICE.

I propose to formalize the concept of category, essentially as a shorthand for a formula. If we have a category with two members, say active and passive, we may take a reference to this category as meaning that one or other, but not both of the properties may appear. This is equivalent to the exclusive disjunction of the members of the category:

(172) $(\mathsf{active} \vee \mathsf{passive}) \wedge \neg(\mathsf{active} \wedge \mathsf{passive})$

So we may define categories as terms in our logic as follows. If a category has the elements $\{\mathsf{p}_1, \ldots, \mathsf{p}_n\}$, then the occurrence of a category name in a formula is equivalent to the formula:

(173) $\bigvee\{\mathsf{p}_1, \ldots, \mathsf{p}_n\} \wedge \neg \bigwedge\{\mathsf{p}_1, \ldots, \mathsf{p}_n\}$

So we may now write formulas of the kind:

(174) $\textsc{voice} \wedge \mathsf{active}$

which in this case will correspond to the specification active. I will refer to statements of this as *cooccurrence restrictions*, following Gazdar *et al* (1985).

We may use this mechanism to enrich our paradigmatic grammar, using cooccurrence restrictions to constrain the class of consistent formulas. One statement that is needed for our description of English is that verb and noun are inconsistent. Therefore, I define the category MAJOR containing them:

(175) MAJOR = {verb, noun}

Other cooccurrence restrictions that might be desirable are left to the imagination of the reader.

To complete this proposal, we have to make a further extension to the definition of a paradigmatic lexicon. This is most easily done by replacing the set P of morphosyntactic categories with the triple, $\langle P, Q, R\rangle$, where P is as before, Q is an association between category names and sets of properties and R is a set of cooccurrence restrictions.

We may now characterize the subparadigm of some item as that part of a lexical entry's exemplary paradigm (124) which is subsumed by some formula:

(176) The subparadigm of some lexical entry $\sigma : \phi$ with respect to a formula ψ and a lexicon L is the set: $\{\sigma' : \phi' | \sigma' : \phi' \in \mathbf{exemplary}(L, \sigma : \phi) \text{ and } \psi \geq \phi'\}$

So, from our analysis of English (138) above, the subparadigm of ring:verb ∧ base, with respect to the formula participle is

(177) { rung:verb ∧ past ∧ participle,
rung:verb ∧ passive ∧ participle,
ringing:verb ∧ present ∧ participle }

Composite Rules

The previous discussion permits us to provide a more useful characterization of the notion of morphosyntactic operation. In place of a single lexical rule, we may state more complex relations between morphosyntactic specifications. Recalling the discussion of Section 2.1.1, I stated that non-defeating lexical rules were commutative. In other words, the order of application of non-defeating lexical rules is irrelevant to the result of application. This is not the case for defeating lexical rules. If $\mathbf{r}$ and $\mathbf{r}'$ are defeating lexical rules, then the following will not necessarily hold:

(178) $\mathbf{r}(\mathbf{r}'(\phi)) = \mathbf{r}'(\mathbf{r}(\phi))$

In the case of non-defeating rules since (178) will hold, it makes sense to speak of *conjunctions* of such rules. However, if we wish to combine defeating and non-defeating rules, we have to define what the result of combination is. I will introduce a new operator ';' for this purpose.

(179) If $\mathbf{r}_1$, $\mathbf{r}_2 \ldots \mathbf{r}_n$ are lexical rules, then $\mathbf{r}_1; \mathbf{r}_2; \ldots; \mathbf{r}_n$ is a *composite lexical rule.*

(180) The result of application of a composite lexical rule $\mathbf{r}_1; \mathbf{r}_2; \ldots; \mathbf{r}_n(\phi)$ is the set of consistent formulas that results from the application of $\mathbf{r}_1$, $\mathbf{r}_2 \ldots \mathbf{r}_n$ to ϕ *in any order.*

There are a number of cases of interest here which follow from the definition of rule application in (100). If the rules of which a composite lexical rule is composed are of the form $\mathbf{rule} = \langle \mathsf{true}, \psi \rangle$, the result will simply be (the singleton set consisting of) the conjunction of all the consequents of the rules if they are mutually consistent and consistent with ϕ. If one of the rules $\mathbf{r}_n$ is of the form $\langle \psi, \psi' \rangle$ and the rest of them are non-defeating, then the result will be defined and be a singleton set, just in case the composition of the rules excluding $\mathbf{r}_n$ applied to ϕ results in a formula subsumed by ψ.

If any rule in a composite rule R is defeating, i.e. of the form $\mathbf{rule} = \langle \psi, \psi' \rangle$ where $\psi \not\geq \psi'$, the result of application of the composite rule will be defined in case some subset of the rules R' applied to ϕ yields a formula which is subsumed by ψ.

The force of the above definitions is to abstract away from any concrete ordering given in a particular composite rule, and following the discussion of Section 2.1.1, to prohibit any possibility of the extrinsic ordering of lexical rules.

Composite rules, in effect, make new rules out of old, and allow us to factor out common properties of rules. Thus, a lexical rule such as (181) might be factored into its component parts (182) and then reinstated as the composite rule (183):

(181) $\mathbf{progressive} = \langle \mathsf{true}, \mathsf{participle} \wedge \mathsf{progressive} \rangle$

(182) $\mathbf{prog} = \langle \mathsf{true}, \mathsf{progressive} \rangle$
$\mathbf{participle} = \langle \mathsf{true}, \mathsf{participle} \rangle$

(183) **prog; participle**

Composite rules are used extensively in the analysis of Latin presented in Appendix A.

Defectiveness

With the above definition of composite lexical rules, we may give a tentative answer to the problem of defectiveness, mentioned in **3.3**. The proposal I will make here (*pace* Matthews 1965a) is that defectiveness is essentially a lexical phenomenon. To resume the example of French *clore* "close" and *enclore* "enclose", the former has no first person plural form, **nous closons*, whereas the latter has *nous enclosons*. The fact that a particular lexical entry presents no form associated with some morphosyntactic specification whereas other lexical entries comparable in other respects do present a form suggests strongly that the difference is to be isolated within the lexical entry, rather than within the mechanisms responsible for the relations between forms.

The proposal I will make here is that an entry such as *clore* will have a morphosyntactic specification which is subsumed by the formula

(184) $\neg(\mathsf{first} \wedge \mathsf{plural})$

In this case, any rules which jointly add the specifications first and plural will result in an inconsistent specification, thereby preventing the derivation of a form such as *closons*. *enclore* would not be so marked and would therefore allow the relevant derivation. One assumption is required for the above proposal to go through, namely that such specifications which mark items as defective are not defeated in the application of rules.

This is not to say that "gaps in the paradigm" can arise only through specification in the base lexicon. Under the definition of the application of lexical rules given above, a rule may fail to be applicable in virtue of its morphosyntactic specification, i.e. the specification does not subsume the specification of the item in question. This would arise in the case of intransitive verbs if we further specified the rule **passive** (163) to require its input to have the specification **transitive**. Under this view then, defectiveness has arguably some of the same properties as productivity (Section 1.5).

Relevance

In the definition of derivability in Section **3.1.1**, I promised to give a definition of *relevance*, to justify the statement there that a paradigm contains all information relevant to a particular paradigmatic word (modulo the abbreviatory possibilities discussed in Section 3.3). The definition itself is extremely simple. For the purposes of determining the content of a paradigm **p**,

(185) a morphosyntactic specification ϕ' is ***relevant*** to another ϕ, the morphosyntactic specification of **p**, if ϕ' can be derived by some (composite) lexical rule from ϕ, and there is no paradigm $\mathbf{p}'$ such that $\mathbf{p} > \mathbf{p}'$ and the paradigmatic word of $\mathbf{p}'$ morphosyntactically subsumes ϕ'.

In the case of non-defeating lexical rules, ϕ' will be relevant to ϕ if it is a consistent extension of ϕ. The justification for this definition is that we may view the paradigmatic word as representing a locus for generalizations. The paradigmatic words may, as discussed above, be underspecified. We are therefore interested in any way that we might further specify it. However, if there is some more specific paradigm, this will be the locus of generalization for that particular morphosyntactic specification.

3.4 Summary

In this chapter, I have presented a formal system for the description of morphological information based on the traditional notion of paradigm. I have furthermore shown what abbreviatory mechanisms are available to us to allow the more concise representation of such information.

Chapter 4

Inflecting and Agglutinating Languages

Hockett (1954) contends that approaches to the morphology of natural languages based on inflectional morphology and using paradigmatic formulations fail to provide a useful model for the treament of non-inflecting languages. This is a criticism which Matthews (1972, p147-156) concedes. In particular, Matthews suggests that it would seem "entirely perverse" to attempt a treatment of a language such as Turkish within the framework of WP (op cit p148). The aim of this chapter is to demonstrate that the case for making insuperable distinctions between WP and Item and Process (IP) morphology or for that matter Item and Arrangement (IA) morphology is much less strong within the framework I am proposing than has been previously suggested for systems that make use of paradigms. I will argue that the suitability of a paradigmatic treatment is determined by the extent to which a language presents morphological alternations which are dependent on some "clustering" of orthographic and morphosyntactic information.

The main point to be made here is that, while there may be good grounds for preferring a particular *style of presentation* to describe the morphological facts of a certain language, there is no reason to suppose that the *formal apparatus* required to interpret such a presentation differs, as those facts differ from language to language. To use a very simple analogy, we have a choice in how we represent numbers: arabic numerals are convenient for arithmetic, assigning a constant meaning to position and form. In other situations, roman numerals may be required by convention, and may have the advantage, at least in some cases, of affording a more compact representation. Either system may be interpreted by some formalization of the natural numbers. So I hope to demonstrate that the basic stock of concepts I have introduced in the previous chapter are sufficient to the task of characterizing languages of a character radically different to that of Latin. Such a demonstration can be seen to add substantive content to the claim of Thomas-Flinders (1981b) that morphological theory can be developed in a way that does not prefer languages of a particular kind, say inflecting languages over agglutinating languages.

This chapter has the following structure. First, I will indicate how the specification of orthographic and morphosyntactic alternations may be used to derive rules in a *morpholexical* format, similar to those proposed by Matthews (1972, Ch. 9), Anderson (1982), Spencer (1988) *inter alia*. Second, I will show, following the discussion of Section 2.4.1, that a description phrased in terms of Paradigmatic Morphology involving the Elsewhere Condition may be transformed into related systems which do not make reference to the Condition. Both of these techniques will be illustrated using examples drawn from the analysis of the previous chapter. The applicability of the resulting systems to agglutinating languages will be exemplified by a brief analysis of the morphology of Turkish. This chapter concludes with a discussion of Semitic intercalating or transfixational morphology.

4.1 Paradigms and Morpholexical Rules

In my previous definitions of lexical rules in 3.(100) and 3.(180), I made the assumption that lexical rules had no information about string forms associated with them and that string relations are given solely by the paradigms. This assumption was made simply to make the formal description of the system easier. In fact, we may make the first step required here by recasting the system presented in Chapter 3 and saying that the string information associated with a paradigm is redundantly associated with any lexical rule mentioned by the paradigm. Technically, this is just the composition of the instances of string forms in the paradigm with the lexical rule. So if we have a paradigm of the form shown in (186),

(186) $\langle \sigma : \phi, \langle \ldots \mathbf{r} \ldots \rangle, \langle \ldots \tau \ldots \rangle \rangle$

the corresponding *morpholexical rule* is (187):

(187) $\langle \sigma : \phi, \tau{:}\mathbf{r}(\phi) \rangle$

That is, a morpholexical rule represents a mapping between lexical specifications. More concretely, consider the following example, seen above as 3.(160). (189) is the morpholexical rule that corresponds to the paradigm (188):

(188) **verb age**
age:verb ∧ base
progressive ageing

(189) $\langle$age : verb ∧ base, ageing : **progressive**(verb ∧ base)$\rangle$

For morpholexical rules in this form, we may phrase a definition of derivability essentially similar to, but somewhat simpler than that for derivation via a paradigm given in (120).

(190) Given a lexical specification $\sigma : \phi$ and a morpholexical rule $\langle \sigma' : \phi', \tau : \mathbf{r}(\phi) \rangle$, if $\sigma' : \phi' \geq \sigma : \phi$, then we may derive another lexical specification $\tau' : \psi$, where $\sigma \wedge_s \sigma' \rightarrow \tau = \tau'$ and $\psi = \mathbf{r}(\phi)$.

In this format, the statements we may derive from paradigms bear considerable similarity to the elements found in a categorial grammar (cf. Hoeksema 1985). That is, we may interpret a morpholexical rule in the form shown in (187) as a function from formulas to formulas, which states morphosyntactic conditions on the application. The string specifications give a "recipe" by which to construct an orthographic form. With this minor difference, (190) is in essence the standard definition of function application in a categorial grammar.

While we have seen that something familiar results from the transformation discussed above, we need to determine that the alternative formulation is actually faithful to the original. In other words, are there further conditions that are needed in order to guarantee that our new formulation allows all derivations that were allowed under the previous formulation and no others? Obviously the most crucial difference is that (190) does not implement any form of the Elsewhere Condition, and that we are therefore in danger of allowing regular derivations that should be blocked by a more specific statement. The course taken by Hoeksema (1985, p23) is open to us, and we might thereby add a condition to the definition of derivation above:

(191) Given a lexical specification $\sigma : \phi$ and a morpholexical rule $\langle \sigma' : \phi', \tau : \mathbf{r}(\phi) \rangle$, if $\sigma' : \phi' \geq \sigma : \phi$, then we may derive another lexical specification as in (190), unless there is some other morpholexical rule $\langle \sigma'' : \phi'', \tau' : \mathbf{r}(\phi'') \rangle$ and $\sigma' : \phi' > \sigma'' : \phi'' \geq \sigma : \phi$.

However, rather than explore this possibility, I will follow the route described in Section 2.4.1, and work in terms of a system where the Elsewhere Condition has been removed as a condition of application.

4.2 Transformations on paradigms

In Chapter 3, I introduced the relation of subsumption and the ordering over paradigms that this relation induces. Consider the following paradigms, which are a subset of those in 3.(126) to (130):

(192) **verb**

s:verb $\wedge$ base

base	s
3sg	s+s
non3sg	s
past participle	s+ed
past	s+ed
progressive	s+ing

(193) **verb in e**

s+e:verb $\wedge$ base

past participle	s+ed
past	s+ed
progressive	s+ing

(194) **verb age**

age:verb $\wedge$ base

progressive	ageing

The subsumption relations holding between these paradigms is shown in Figure 4–1. We may now apply the transformation discussed in 2.(57) to these paradigms, resulting in those shown in (195) to (197):

(195) **verb**

s:verb $\wedge$ base where $\underline{s \wedge_s \neg(x+\mathrm{e})}$

base	s
3sg	s+s
non3sg	s
past participle	s+ed
past	s+ed
progressive	s+ing

$$\begin{array}{c} \top \\ | \\ s\text{:verb} \wedge \text{base} \\ | \\ s{+}\text{e:verb} \wedge \text{base} \\ | \\ \text{age:verb} \wedge \text{base} \\ | \\ \bot \end{array}$$

Figure 4–1: Subsumption Relations between the paradigms (192) to (194)

(196) **verb in e**

s+e:verb $\wedge$ base where $\underline{s \wedge_s \neg\text{age}}$

3sg	s+es
past participle	s+ed
past	s+ed
progressive	s+ing

(197) **verb age**

age:verb $\wedge$ base

progressive ageing

These versions are just like those above, with the exception of the underlined constraints in the lexical specification of each paradigm. For each paradigm, these additional constraints will be seen to be the negation of the constraints in the paradigm that it most directly subsumes. Crucially, they are precisely those constraints that represent the differences between a paradigm and any directly subsumed paradigm. The relation of subsumption now induces the lattice in Figure 4–2.

This lattice is "flat"—there is no element in the lattice (lower than $\top$) which subsumes another consistent element. In this case, the second clause in the definition

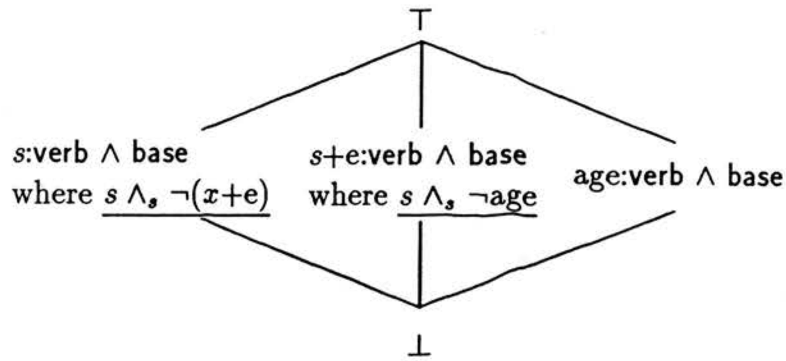

Figure 4–2: Subsumption Relations between paradigms (195) to (197)

of derivation via a paradigm 3.(120) is redundant, as the situation it describes can never arise. Likewise, if we now transform these paradigms into morpholexical rules, the definition given in (190) need not be further restricted. Formally, we may state the transformation from a set of paradigms which requires the EC to one which does not as follows (cf. 2.(57)). I will term a set of paradigms which does not require the EC to hold a set of *non-preempting* paradigms.

(198) Let Π be a set of paradigms, $\succ$ be the relation of direct subsumption defined in (149) holding between the paradigms and $\mathbf{covers(p)} = \{\mathbf{p'}|\mathbf{p} \succ \mathbf{p'}\}$. Let $\mathbf{pm(p)}$ be the paradigmatic word of $\mathbf{p}$. The set Π' of *non-preempting* paradigms that corresponds to Π is then obtained as follows:
Whenever $\mathbf{p} \in \Pi$ has the paradigmatic word $\sigma : \phi$ and $\mathbf{covers(p)} = \{\mathbf{p}_1, \ldots \mathbf{p}_n\}$, then Π' is just like Π except that the paradigmatic word of $\mathbf{p}$ is replaced by $\sigma : \phi \wedge \bigwedge_{\mathbf{p'} \in \mathbf{covers(p)}} \neg\mathbf{pm(p')}$

The set of morpholexical rules to which a paradigm gives rise is then defined formally in (199):

(199) Let $\mathbf{p} = \langle \sigma : \phi, \langle \mathbf{r}_1, \ldots, \mathbf{r}_n \rangle, \langle \tau_1, \ldots, \tau_n \rangle \rangle$ for $n \geq 1$ be a paradigm drawn from a set Π of non-preempting paradigms. The set of morpholexical rules that $\mathbf{p}$ gives rise to is then:
$\{\langle \sigma : \phi, \tau : \mathbf{r}(\phi) \rangle | \exists i, 1 \leq i \leq n, \tau = \tau_i \wedge \mathbf{r} = \mathbf{r}_i,\}$

4.3 Paradigmatic Morphology and non-inflecting languages

In the system of descriptions presented above, the following statement, often termed *weakening of the consequent*, is a tautology:

(200) $(A \rightarrow B \wedge A \rightarrow C) \leftrightarrow A \rightarrow B \wedge C$

The reconstruction I have presented above of Paradigmatic Morphology can be seen as a formalism which favours instances of the right hand side of this particular statement. For heavily inflecting languages, there is a significant enough correspondence between the antecedents of a set of rules to make it notationally worthwhile to collapse those antecedents in precisely the way licensed by (200); the contexts in which fusion, suppletion or partial suppletion is manifest cluster around particular pairings of string form and morphosyntactic information. We are forced into the position of having to enumerate a number of classes with differing behaviours and to correlate this behaviour with the distribution of inflecting morphemes. On the other hand, in noninflecting languages, as will be discussed shortly, such a presentation of information is redundant in that there are generalizations which can be made without reference to particular orthographic forms; as an example, Turkish inflecting morphemes typically present a form dependent on the stem to which they attach rather than vice versa. Obviously we do not find ourselves presented with the methodological dilemma of determining where WP ends and non-WP starts (Matthews 1972, p148 fn 4), as we have shown that the distinction between the two is an artefact of the morphological systems designed to describe them.

One of the main lessons to be learnt from this discussion is the following: *the paradigmatic and morpholexical modes of description are not incompatible.* That is, we may phrase a description of a language in either way according to the facts of the language. In so doing, we do not require the use of formal apparatus in one case which is redundant in the other. Furthermore we have seen how a description in one style may be tranformed into the other.

4.4 Non-inflecting languages

I will now present a small example showing that some of the facts of Turkish may be described in the format of morpholexical rules. This is intended to be purely illustrative and a more substantive analysis would be required to verify the suitability of this approach.

The following example of the morphology of Turkish is taken from Lewis (1967, p30,39) showing the forms of the words *köy* "village" and *son* "end".

(201)

	Sg	Plural
Absolute	köy	köyler
	son	sonlar
Accusative	köyü	köyleri
	sonu	sonları

We may then set up the morpholexical rules in (202) to describe these alternations.

(202) a $\langle c+v+gn{:}\phi,\ \ c+v+gn+\text{ler}{:}\mathbf{Plural}(\phi)\rangle$
where $v \wedge_s$ (i $\vee$ e $\vee$ ü $\vee$ ö), $c \wedge_s$ **Consonant** and $gn \wedge_s$ (**Glide** $\vee$ **Nasal**)

b $\langle c+v+gn{:}\phi,\ \ c+v+gn+\text{lar}{:}\mathbf{Plural}(\phi)\rangle$
where $v \wedge_s$ (a $\vee$ o $\vee$ u $\vee$ ı), $c \wedge_s$ **Consonant**, $gn \wedge_s$ (**Glide** $\vee$ **Nasal**)

c $\langle x+v+gn{:}\ (\phi \wedge \textsf{absolute}),\ x+v+gn+u{:}\ \mathbf{Accusative}(\phi \wedge \textsf{absolute})\rangle$
where $v \wedge_s$ (i $\vee$ e) and $u \wedge_s$ i or
$v \wedge_s$ (ö $\vee$ ü) and $u \wedge_s$ ü or
$v \wedge_s$ (o $\vee$ u) and $u \wedge_s$ u or
$v \wedge_s$ a and $u \wedge_s$ ı

assuming the existence of lexical rules **Plural** and **Accusative**, the latter defeating the description **absolute**. Note that the first and second examples could be conflated by defining a relation of harmony. A partial specification of such a relation is given in the third example.

In the absence of paradigms, we might choose to define an Elsewhere Condition, in the style of Hoeksema (see (191)), over the inputs to morpholexical rules. In this case, we will allow blocking, in that more specific requirements on the input to some rule will prevent a more general rule from applying. On the other hand as discussed in the preceding section, we remove the "clustering" of irregular forms associated with a particular paradigmatic word. In the terminology of Section 3.3.4, there is no need, in agglutinating languages, to set up a paradigmatic word as a locus of generalizations.

4.4.1 Semitic

The Semitic languages, such as Arabic or Hebrew, present substantial problems in morphological analysis (McCarthy 1981). Morphological analysis in traditional grammars (cf. Hudson 1986) recognizes a set of consonantal roots and vocalic melodies. Morphologically complex forms result from the intercalation or transfixation (2.(52)) of a melody into a root. Thus, the root *ktb* "book" or "read" occurs in the following forms (Form I, Hudson 1986):

(203) a *katab*, perfect, active
b *kutib*, perfect passive
c *ktub*, imperfect, active
d *ktab*, imperfect passive
e *kaatib*, participle, active
f *ktuub*, participle, passive

As with the preceding description of Turkish, I shall give illustrative morpholexical rules which allow the description of such phenomena. The same comments apply with respect to the limitations of this analysis.

I will set up the vocalic melodies so that they are functors over roots represented in the traditional manner. Thus, a lexical entry for the root *ktb* would have a form such as (204):

(204) ktb:verb

A vocalic melody that generates the form I, perfect passive is:

(205) $\langle c_1{+}c_2{+}c_3{:}\phi,\ c_1{+}\mathrm{u}{+}c_2{+}\mathrm{i}{+}c_3{:}\mathbf{Perfect\ Passive}(\phi)\rangle$

On the other hand, the following morpholexical rule will generate the form I, participle passive:

(206) $\langle c_1{+}c_2{+}c_3{:}\phi,\ c_1{+}c_2{+}\mathrm{uu}{+}c_3{:}\mathbf{Participle\ Passive}(\phi)\rangle$

These examples are clearly too schematic to be of any use other than to support the assertions of Section 4.3. In particular, they take no account of roots which do not consist of three consonants, or of the "templatic" nature of Semitic morphology.

4.5 Summary

In this chapter, we have seen how formulations using paradigmatic devices may be related to other more familiar methods for the description of morphological behaviour. This assertion was supported by example analyses from non-inflecting langugages. The fact that such a relation exists at the very least offers hope that, contrary to previous assumptions, formalisms for morphological analysis may be devloped which allow the characterization of a variety of language types.

Chapter 5

Conclusions

In this thesis, I have motivated and presented a system for the description of morphology, based largely on the traditional notion of paradigm. After a general review of the necessary formal apparatus, I proceeded by recasting some of the technical devices proposed in Matthews' (1972) treatment of Word and Paradigm Morphology within the kinds of system recently proposed for the logical statement of linguistic theories. Some simple suggestions for increasing the generality of these technical devices were discussed and exemplified. The resulting system then supported an analysis of whether criticisms of paradigm-based theories are justified. I attempted to show that the formal apparatus motivated for a paradigmatic treatment of morphology is closely related to that postulated in other, non-paradigmatic systems. To return to the analogy of Section 1.6, the same bricks and mortar may underpin both paradigmatic and morpholexical styles of architecture.

Relative to Matthews' work, this thesis differs in characterizing relations between orthographic forms as logical relations between descriptions of strings, or equivalently as partial equality expressed in terms of the sharing of variables. Matthews' procedurally defined implementation of the Elsewhere Condition was replaced by an interpretive principle construed in terms of the relative informativeness of two statements. An alternative formulation was given in terms of a theory transformation relating a theory invoking the Elsewhere Condition to one whose interpretation is more standardly logical.

One of the main reflexes of these changes is in the representation of lexemes—the elements of the lexicon. They are now seen as structured, analyzable objects. Morphological behaviour can therefore be characterized in terms of this substructure. This appears, in some of the cases exemplified above and in Appendix A, to obviate the need for setting up abstract classes of lexemes on the basis of differing morphological behaviour. One may then investigate the limit to this process and whether diacritic indication of morphological behaviour may be shown to be unnecessary. The analysis offered in Chapter 3 suggests that some diacritic marking is at least useful. There we saw that the morphosyntactic specification **strong** may be used to condition different behaviour on items that are otherwise identical orthographically and morphosyntactically. If we were to try and strengthen this claim to the point where morphological diacritics were prohibited and all variation were to be ascribed to orthographic or syntactic factors, the kind of descriptive techniques illustrated in this thesis would degenerate in many cases to a catalogue of facts about single lexical items. An instance of this might be found in the different reflexes of nominalization in English, according to a word's source in Germanic or Romance precursors. Little progress has been made in the effort to reduce this variation to non-diacritic factors. So in the current state of play, one would be able only to list highly specific combinations of orthography and syntax, without being able to recognize the generalizations that do hold in terms of suffixation and so on.

An approach which sanctions the use of diacritics is therefore descriptively more adequate, and some general methodological remarks can be thereby elaborated. While we do not at the moment have an explanation for the differential behaviour of English nominalizations, a diacritic approach allows us at least to work with cover terms for the different phenomena. If future work should reveal connections between the different phenomena and other conditioning factors, thereby informing us which of the previously arbitrary choice of diacritic is now to be expected, we may then allow each conditioning factor to imply the appearance of a given diacritic. In effect, an approach which allows us to describe morphological relations in a logical way also allows us to delay decisions about the factors that condition different morphological phenomena. While this approach is not restrictive—it does not seek to limit greatly the form and content of representations which describe morphological behaviour—it is arguably easier in this kind of framework to assess the descriptive adequacy of a proposal, to determine which aspects of a theory are deficient in the face of positive or negative counterexamples and to compare particular theories in their approaches to certain data sets.

There are, of course, numerous respects in which the presentation in this thesis is deficient. One of the least elegant aspects of the formal apparatus is the distinction between string and morphosyntactic descriptions. Their development here has been largely independent, despite the fact that essentially similar algebraic behaviour was ultimately required of descriptions in these domains in order for the technical manoeuvres discussed in Sections 2.4.1 and 4.2.1 to go through. This suggests that a more homogeneous system of description, such as that proposed by Pollard and Sag (1987) or Reape (1989), which allows at least the treatment of both descriptions and sequences of descriptions on an equal footing, would be more perspicuous formally. Such a move would also have advantages for other aspects of this work. For example, the discussion of Matthews' (1972) concept of category in Section 3.3.4 would largely fall out from a treatment of morphosyntactic information in terms of a logic for the description of feature structures.

This thesis has concentrated on the description of orthographic form, following the assumptions made in Matthews (1972). I now turn to the question of the extent to which the conclusions drawn in this thesis carry over into the phonological domain. There are two assumptions of interest here, namely the restriction of the alphabet of symbols to be finite and the strictly linearity of string descriptions. Together these assumptions represent essentially the phonemic position that the phonology of a language may be totally described in terms of the linear arrangement of a finite set of indivisible elements of identical size. Both of these assumptions run somewhat counter to recent trends in phonological theory.

It seems that most researchers do not now question the divisible nature of phonological units, as work over the last sixty years bears witness. Under the assumption that such divisibility is not infinite and that the number of distinct phonological units is therefore finite, the mechanisms of character classes discussed in Section 3.3 would appear to be sufficient to capture any generalizations over such units that may be desired. In many theories, the *segment* appears to have inherited the phoneme's role as the major structuring element in the linearly organized, temporal dimension. On the other hand, the work of McCarthy (1981) amongst others suggests that units of differing and possibly indeterminate size may be of use in phonological description. More specifically, a particular phonological property may be postulated to hold of stretches of material longer than a segment. This property of descriptions is more difficult to encode within the formal mechanisms I described in Chapters 3 and 4, as the discussion on page 83 might suggest. There, we saw that generalizations may only be made over strings of known lengths, but also that technical solutions are known to ameliorate this situation.

The question of the linearity of phonological descriptions seems to me to be more problematic and more interesting. In this thesis, we have taken advantage of the observed fact that orthographic objects are linearly organized to elaborate a simple mathematical model for such objects. Theories such as McCarthy's (1981) non-concatenative morphology, while not strictly linear, are arguably still *quasilinear* in that a strict linear ordering is required to hold between segments and between all elements of any level of analysis (or *tier*) postulated by the theory. The only nonlinearity witnessed by such a theory holds of the relation between elements on different tiers.

A radical alternative to the quasilinear view, in essence dating back at least to Firth (1948), holds that linearity we might witness in the phonetic domain need not imply that the same linear ordering, or indeed any ordering derived from temporality, is justified in the phonological domain. Rather, such linearity is imposed by the requirement that a phonological expression is in correspondence with its possible phonetic realizations and phonological expressions themselves may contain little or nothing that directly reflects linear ordering. Under this view, a possible criticism of my system of orthographic representation is that it conflates properties which derive from the medium of writing with others that derive from the linguistic system proper, such as the terms that represent the phonological distinctions made in some language.

I would counter this objection with the hope that one of the advantages of the position taken in this thesis is that I have been sufficiently abstract to allow the results of the discussions in Chapter 4 to be applicable in settings where different choices are made as to the form and content of phonological and morphosyntactic descriptions. In particular, the result that paradigmatically stated relations have an equivalent formulation in terms of morpholexical rules may be assumed to hold in any formalism in which weakening of the consequent is a tautology and in which morphological relations may be interpreted as logical implications. Likewise, the theory transformation which allows us to remove the Elsewhere Condition as a principle of interpretation is available in any system which offers an ordering given by logical consequence and the negation of arbitrary expressions. These conditions are from a logical point of view relatively weak, and we may therefore hope that the descriptive devices they permit can be reconstructed in any formalism which meets them, regardless of concrete decisions taken as to the form and content of linguistic information. To resume the analogy of my introduction, there are many ways in which an architectural plan may be executed and the result will in many cases be indifferent to the materials employed.

There remain cases when the technical choices made here lead to some difficulties with the concise expression of the generalizations we require. In particular, while the notion of default defined in 3.3 allows us to abbreviate in situations where statements made at a more general level are also true in more specific situations, it fails to capture partial, independently conditioned generalizations about string forms. A case in point is the description of Latin shown in Appendix A, where stems may present different forms internally but combine with a set of regular suffixes. This is a result of identifying the dimension of inheritance with that induced by the relation of paradigmatic subsumption. As discussed above, a system such as DATR, which allows inheritance to be defined along multiple dimensions, is at a considerable advantage here. The definition of more powerful inheritance mechanisms and their interaction with systems of partial information is an outstanding question in a number of fields.

The topics raised in Chapter 4 pose some interesting further questions about the description of languages of different morphological types. In that chapter, we discussed a variety of mechanisms for reconciling the styles of description suggested by agglutinating and inflecting languages. While the formal links between paradigmatic and morpholexical formulation are relatively clear, the examples given here are insufficient to show that there is an interesting correspondence between these formulations in the general case. Further research might consider the morphological behaviour of mixed systems to determine the descriptive choices in the context of both paradigmatic and morphological statements. A more general topic that also arises, as our morphological statements have tended in Chapter 4 towards the same scheme as witnessed in Categorial Grammar, is the difference between morphological and syntactic behaviour and the extent to which the same general principles may hold in both.

To speak more generally, I hope that this work will find its place in what I discern to be a growing interest in linguistics, namely that of theory comparison and evaluation, in terms primarily of the behaviour of theories over particular data sets, but also of the devices which lend descriptive force to theories. By charting out some of the options available to descriptive systems, encoding these options formally and comparing the descriptive devices that are thereby made available with those found in other theories, we may further our understanding of the relative importance of the various devices and the extent to which each contributes to our understanding of human language.

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Appendix A

Description of Latin using Paradigmatic Morphology

In this Chapter I shall give a description of Latin verbal morphology using the devices discussed above. The data covered in this section are taken from Gildersleeve and Lodge (1895) with suppression of some information to do with the length of vowels.

The overall "shape" of the analysis is shown in Figure A, in terms of the subsumption relations holding between the groups of paradigms defined below. Contrary to the position of traditional grammars and the work of Matthews, I do not take the first person singular, present indicative, for example *amō*, as the form on which to base the paradigmatic word. Instead, the paradigmatic word is taken to be the same form as that found in the present infinitive, in the above case *amāre*. The justification for this is that the infinitive gives an indication of conjugation class in terms of the vowel that precedes the infinitival suffix.

This analysis is not exhaustive; it does not attempt to cover those forms with "irregular" infinitives, such as *velle* "be willing" or *ferre* "bear" and its compounds. It does however cover the four traditional conjugations, and a number of the minor irregularities. I trust it will be clear how the analysis could be further extended. Notable omissions are the classes of inchoative and nasal verbs.

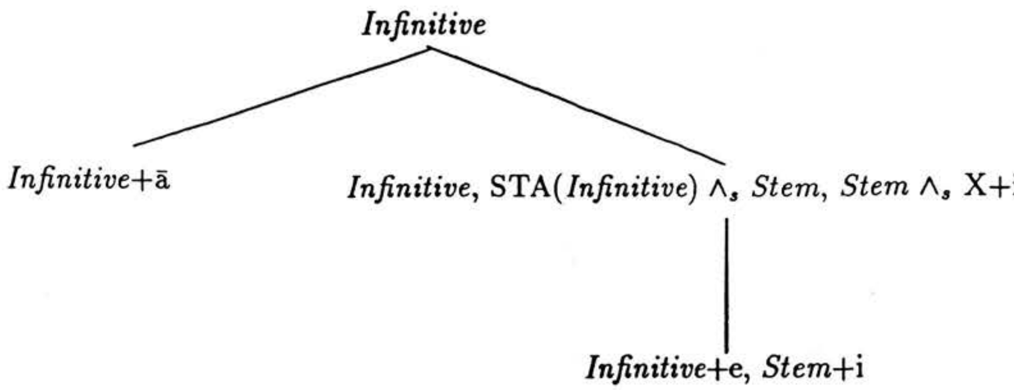

Figure A–1: Subsumption relations holding between the paradigms of Tables A–1 to A–5

For the analysis of deponents, verbs which "have the passive form but are active in meaning" (Gildersleeve and Lodge 1895, p85), it appears easiest within the analysis developed below to treat them as defective (cf. the discussion in 3.3.4). That is, deponents will be lexically marked with the property passive, thereby prohibiting the derivation of any form bearing the property active. This is probably an undesirable move, as it forces us to give a deponent such as *hortāri*, "exhort", a lexical string specification "hortāre" which is found nowhere in the corresponding paradigm.

A.1 Preliminaries

I shall follow the same conventions for the representations of paradigms as used in the previous chapter. I shall assume the following definitions of character classes

(207) a **Consonant** = $\bigvee$\{b, c, d, f, g, h, l, m, n, p, q, r, s, t, x\}
b **Vowel** = $\bigvee$\{a, e, i, o, u, ā, ē, ī, ō, ū\}

and I will write $x \wedge_s$ **Vowel**. Note that I am treating a vowel and its length diacritic (¯) as a single symbol. I shall also assume the existence of the following functions.

The first of these defines the "shortening" function, which relates a character that represents a long or a short vowel to the character representing the corresponding short vowel. In other words, it is an identity function for short vowels. The second function is the "lengthening" function, with a similar definition.

$$\text{(208)}\quad \text{a}\quad \textbf{short} = \{\ \begin{array}{l} \langle \bar{\text{a}}, \text{a} \rangle \\ \langle \text{a}, \text{a} \rangle \\ \langle \bar{\text{e}}, \text{e} \rangle \\ \langle \text{e}, \text{e} \rangle \\ \ldots \} \end{array}$$

$$\text{b}\quad \textbf{long} = \{\ \begin{array}{l} \langle \bar{\text{a}}, \bar{\text{a}} \rangle \\ \langle \text{a}, \bar{\text{a}} \rangle \\ \langle \bar{\text{e}}, \bar{\text{e}} \rangle \\ \langle \text{e}, \bar{\text{e}} \rangle \\ \ldots \} \end{array}$$

The function **STA**(*Infinitive*, *Stem*) (for Stem-Theme Alternation) represents the traditional statement that there is an alternation between the vowel found in the infinitive form of a lexical entry and some vowel found in certain positions in the paradigm.

$$\text{(209)}\quad \textbf{STA} = \{\ \begin{array}{l} \langle \mathit{String}+\bar{\text{a}}, \mathit{String}+\text{a} \rangle \\ \langle \mathit{String}+\bar{\text{e}}, \mathit{String}+\text{e} \rangle \\ \langle \mathit{String}+\bar{\text{i}}, \mathit{String}+\text{i} \rangle \\ \langle \mathit{String}+\text{e}, \mathit{String}+\text{i} \rangle \\ \langle \mathit{String}+\text{a}, \mathit{String}+\text{a} \rangle\ \} \end{array}$$

I will assume the existence of a number of other classes whose definition should be obvious, e.g. **Nasal**. Of the other components of a paradigmatic grammar, I give the following partial specifications.

Morphosyntactic properties

The morphosyntactic properties recognized by the grammar are:

1, 2, 3 as terms in the category PERSON.

ablative, accusative, dative, genitive, nominative as terms in the category CASE.

supine, gerund as terms in the category NOMINAL.

active, **passive** as terms in the category VOICE.

plural, **singular** as terms in the category NUMBER.

future, **future perfect**, **imperfect**, **perfect**, **pluperfect**, **present** as terms in the category TENSE.

infinitive, **participle** as terms in the category UNTENSED.

indicative, **imperative**, **subjunctive** as terms in the category VOICE.

The morphosyntactic properties **deponent** and **transitive** will not be assigned to categories.

The following cooccurrence restrictions hold of all morphosyntactic descriptions:

verb $\leftrightarrow \neg$ NOMINAL

verb $\leftrightarrow$ TENSE $\vee$ UNTENSED

verb $\leftrightarrow$ VOICE

NOMINAL $\rightarrow$ CASE

Lexical entries

amāre: verb $\wedge$ transitive

delēre: verb $\wedge$ transitive

emere: verb $\wedge$ transitive

capere: verb $\wedge$ transitive

audīre: verb $\wedge$ transitive

hortāre: verb $\wedge$ deponent

The definition of closure of the lexicon is assumed to be exclusive (cf. (122)).

Lexical rules

For every morphosyntactic property, there is a corresponding lexical rule. With the exception of the rules **Supine** and **Gerund**, these are non-defeating rules, and so take the form

(210) **Ablative** = ⟨true, ablative⟩

The other two rules are defeating with respect to the property verb.

(211) **Gerund** = ⟨verb, gerund⟩

(212) **Supine** = ⟨verb, supine⟩

Note that as these two rules appear in composite lexical rules below, their application will have to precede application of rules such as **Ablative**, in order to defeat the specification verb and be consistent with a specification such as ablative.

I now turn to a discussion of the paradigms.

A.2 The Most General Paradigms

Tables A–1 to A–5 are what I shall term for obvious reasons the "most general" paradigms. Note that the conditions placed on the paradigmatic word are identical in each of these cases. This is simply for ease of notation—under the definitions given above, the paradigms will give rise to the same derivations as they would, were the information combined in them combined.

The paradigms are based primarily on the Second Conjugation. The first (A–1) describes the morphology of present indicative forms and various others that will be made use of by the subsidiary paradigms in Section A.2.1, (A–2) subjunctive, (A–3) future, (A–4) imperatives and (A–5) non-finite forms of the verb. Further comments appear with each table. Note in particular that the paradigm A–1 contains specifications of active imperfect and perfect forms designed to "feed"

Present and Imperfect Indicative

Infinitive+re:verb where

STA(*Infinitive*, *Stem*)

Active;	Present;	Indicative;	Singular;	1	*Stem*+ō
Active;	Present;	Indicative;	Singular;	2	*Infinitive*+s
Active;	Present;	Indicative;	Singular;	3	*Stem*+t
Active;	Present;	Indicative;	Plural;	1	*Infinitive*+mus
Active;	Present;	Indicative;	Plural;	2	*Infinitive*+tis
Active;	Present;	Indicative;	Plural;	3	*Stem*+nt
Passive;	Present;	Indicative;	Singular;	1	*Stem*+or
Passive;	Present;	Indicative;	Singular;	2	*Infinitive*+(ris ∨ re)
Passive;	Present;	Indicative;	Singular;	3	*Infinitive*+tur
Passive;	Present;	Indicative;	Plural;	1	*Infinitive*+mur
Passive;	Present;	Indicative;	Plural;	2	*Infinitive*+minī
Passive;	Present;	Indicative;	Plural;	3	*Stem*+ntur
Active;	Imperfect;	Indicative;	Singular;	1	*Infinitive*+bam
Active;	Perfect;	Indicative;	Singular;	1	*Infinitive*+ī

Table A–1: Present and Imperfect Indicative

other subsidiary paradigms. As discussed above, the choice of the form "*Infinitive*+bam" as a representative of the class of imperfect forms is arbitrary. Pete Whitelock has suggested to me that this arbitrariness might be removed by postulating a form such as "*Infinitive*+b+*Suffix*", and by adding a well-formedness condition on derived items that their string specifications be ground. Such a move may be of use here but would require too much revision of technical apparatus for proper consideration here.

Note that in the case of the subjunctive forms we construct four extra strings, corresponding to the form presented by the present and imperfect first and second persons. These strings do not constrain the paradigmatic word and therefore do not affect the subsumption relations shown in Figure A.

A.2.1 Subsidiary Paradigms

As the paradigms of the imperfect, perfect and non-finite forms show little or no irregularity relative to some member of the paradigms described above, we use the subsidiary paradigms in A–6 to A–9 to describe their behaviour. The

Subjunctive Forms

Infinitive+re:**verb** where

STA(*Infinitive, Stem*)

$Subj_1 \wedge_s Stem$+a

$Subj_2 \wedge_s Stem$+ā

$ImpSubj_1 \wedge_s Infinitive$+re

$ImpSubj_2 \wedge_s Infinitive$+rē

Active;	Present;	Subjunctive;	Singular;	1	$Subj_1$+m
Active;	Present;	Subjunctive;	Singular;	2	$Subj_2$+s
Active;	Present;	Subjunctive;	Singular;	3	$Subj_1$+t
Active;	Present;	Subjunctive;	Plural;	1	$Subj_2$+mus
Active;	Present;	Subjunctive;	Plural;	2	$Subj_2$+tis
Active;	Present;	Subjunctive;	Plural;	3	$Subj_1$+nt
Active;	Imperfect;	Subjunctive;	Singular;	1	$ImpSubj_1$+m
Active;	Imperfect;	Subjunctive;	Singular;	2	$ImpSubj_2$+s
Active;	Imperfect;	Subjunctive;	Singular;	3	$ImpSubj_1$+t
Active;	Imperfect;	Subjunctive;	Plural;	1	$ImpSubj_2$+mus
Active;	Imperfect;	Subjunctive;	Plural;	2	$ImpSubj_2$+tis
Active;	Imperfect;	Subjunctive;	Plural;	3	$ImpSubj_1$+nt
Passive;	Present;	Subjunctive;	Singular;	1	$Subj_1$+r
Passive;	Present;	Subjunctive;	Singular;	2	$Subj_2$+(ris ∨ re)
Passive;	Present;	Subjunctive;	Singular;	3	$Subj_2$+tur
Passive;	Present;	Subjunctive;	Plural;	1	$Subj_2$+mur
Passive;	Present;	Subjunctive;	Plural;	2	$Subj_2$+minī
Passive;	Present;	Subjunctive;	Plural;	3	$Subj_1$+ntur
Passive;	Imperfect;	Subjunctive;	Singular;	1	$ImpSubj_1$+r
Passive;	Imperfect;	Subjunctive;	Singular;	2	$ImpSubj_2$+(ris ∨ re)
Passive;	Imperfect;	Subjunctive;	Singular;	3	$ImpSubj_2$+tur
Passive;	Imperfect;	Subjunctive;	Plural;	1	$ImpSubj_2$+mur
Passive;	Imperfect;	Subjunctive;	Plural;	2	$ImpSubj_2$+minī
Passive;	Imperfect;	Subjunctive;	Plural;	3	$ImpSubj_1$+ntur

Table A–2: Subjunctive Forms

Future Forms

Infinitive+re:verb where

STA(*Infinitive*, *Stem*)

Active;	Future;	Singular;	1	*Infinitive*+bō
Active;	Future;	Singular;	2	*Infinitive*+bis
Active;	Future;	Singular;	3	*Infinitive*+bit
Active;	Future;	Plural;	1	*Infinitive*+bimus
Active;	Future;	Plural;	2	*Infinitive*+bitis
Active;	Future;	Plural;	3	*Infinitive*+bunt
Passive;	Future;	Singular;	1	*Infinitive*+bor
Passive;	Future;	Singular;	2	*Infinitive*+be+(ris ∨ re)
Passive;	Future;	Singular;	3	*Infinitive*+bitur
Passive;	Future;	Plural;	1	*Infinitive*+bimur
Passive;	Future;	Plural;	1	*Infinitive*+biminī
Passive;	Future;	Plural;	3	*Infinitive*+buntur

Table A–3: Future Forms

Imperative forms

Infinitive+re:verb where

STA(*Infinitive*, *Stem*)

Active;	Present;	Imperative;	Singular;	2	*Infinitive*
Active;	Present;	Imperative;	Plural;	2	*Infinitive*+te
Active;	Future;	Imperative;	Singular;	2	*Infinitive*+tō
Active;	Future;	Imperative;	Singular;	3	*Infinitive*+tō
Active;	Future;	Imperative;	Plural;	2	*Infinitive*+tōte
Active;	Future;	Imperative;	Plural;	3	*Stem*+ntō
Passive;	Present;	Imperative;	Singular;	2	*Infinitive*+re
Passive;	Present;	Imperative;	Plural;	2	*Infinitive*+minī
Passive;	Future;	Imperative;	Singular;	2	*Infinitive*+tor
Passive;	Future;	Imperative;	Singular;	3	*Infinitive*+tor
Passive;	Future;	Imperative;	Plural;	3	*Stem*+ntor

Table A–4: Imperative forms

Non-finite forms

Infinitive+re:verb where

STA(*Infinitive*, *Stem*)

Active;	Infinitive;	Present	*Infinitive*+re
Active;	Gerund;	Nominative	*Infinitive*+re
Active;	Gerund;	Genitive	*Stem*+ndī
Active;	Supine;	Accusative	*Infinitive*+tum
Passive;	Infinitive;	Present	*Infinitive*+rī

Table A–5: Non-finite forms

Imperfect Forms

Infinitive+bam:active ∧ imperfect ∧ indicative ∧ singular ∧ 1

Active;	Imperfect;	Indicative;	Singular;	2	*Infinitive*+bās
Active;	Imperfect;	Indicative;	Singular;	3	*Infinitive*+bat
Active;	Imperfect;	Indicative;	Plural;	1	*Infinitive*+bāmus
Active;	Imperfect;	Indicative;	Plural;	2	*Infinitive*+bātis
Active;	Imperfect;	Indicative;	Plural;	3	*Infinitive*+bant
Passive;	Imperfect;	Indicative;	Singular;	1	*Infinitive*+bar
Passive;	Imperfect;	Indicative;	Singular;	2	*Infinitive*+bā+(ris ∨ re)
Passive;	Imperfect;	Indicative;	Singular;	3	*Infinitive*+bātur
Passive;	Imperfect;	Indicative;	Plural;	1	*Infinitive*+bāmur
Passive;	Imperfect;	Indicative;	Plural;	2	*Infinitive*+bāminī
Passive;	Imperfect;	Indicative;	Plural;	3	*Infinitive*+bantur

Table A–6: The subsidiary paradigm of Imperfect forms

first (A–6) describes the paradigm of the passive and active imperfect indicative, while (A–7) describes the perfect and pluperfect. These descriptions are related to the corresponding first person singular described in A–1. The third and fourth subsidiary paradigms (A–8) and (A–9) describe non-finite forms. They are related to the definitions given above of the genitive form of the gerund, and the accusative supine.

Note that, as each of these paradigms contains a morphosyntactic description as part of the paradigmatic word which is not found in any of the others, there are no interesting subsumption relations that hold between them.

It will be noted that the description of forms related to the Gerund requires the construction of a new string, *St*+*w* for the description of the nominal form of the present participle. This is because of the long vowel shown in this form by the Fourth conjugation forms such as *audiēns.* The vowel "ē" is, in this case, unrelated to the stem vowel "ī". Note also the form of *emere*, *emēns.*

Perfective Forms

Perfective+ī: active ∧ perfect ∧ indicative ∧ singular ∧ 1

Active;	Perfect;	Indicative;	Singular;	2	*Perfective*+istī
Active;	Perfect;	Indicative;	Singular;	3	*Perfective*+it
Active;	Perfect;	Indicative;	Plural;	1	*Perfective*+imus
Active;	Perfect;	Indicative;	Plural;	2	*Perfective*+istis
Active;	Perfect;	Indicative;	Plural;	3	*Perfective*+(ērunt ∨ ēre)
Active;	Perfect;	Subjunctive;	Singular;	1	*Perfective*+erim
Active;	Perfect;	Subjunctive;	Singular;	2	*Perfective*+eris
Active;	Perfect;	Subjunctive;	Singular;	3	*Perfective*+erit
Active;	Perfect;	Subjunctive;	Plural;	1	*Perfective*+erimus
Active;	Perfect;	Subjunctive;	Plural;	2	*Perfective*+eritis
Active;	Perfect;	Subjunctive;	Plural;	3	*Perfective*+erint
Active;	Pluperfect;	Indicative;	Singular;	1	*Perfective*+eram
Active;	Pluperfect;	Indicative;	Singular;	2	*Perfective*+erās
Active;	Pluperfect;	Indicative;	Singular;	3	*Perfective*+erat
Active;	Pluperfect;	Indicative;	Plural;	1	*Perfective*+erāmus
Active;	Pluperfect;	Indicative;	Plural;	2	*Perfective*+erātis
Active;	Pluperfect;	Indicative;	Plural;	3	*Perfective*+erant
Active;	Pluperfect;	Subjunctive;	Singular;	1	*Perfective*+issem
Active;	Pluperfect;	Subjunctive;	Singular;	2	*Perfective*+issēs
Active;	Pluperfect;	Subjunctive;	Singular;	3	*Perfective*+isset
Active;	Pluperfect;	Subjunctive;	Plural;	1	*Perfective*+issēmus
Active;	Pluperfect;	Subjunctive;	Plural;	2	*Perfective*+issētis
Active;	Pluperfect;	Subjunctive;	Plural;	3	*Perfective*+issent
Active;	Future Perfect;		Singular;	1	*Perfective*+erō
Active;	Future Perfect;		Singular;	2	*Perfective*+eris
Active;	Future Perfect;		Singular;	3	*Perfective*+erit
Active;	Future Perfect;		Plural;	1	*Perfective*+erimus
Active;	Future Perfect;		Plural;	2	*Perfective*+eritis
Active;	Future Perfect;		Plural;	3	*Perfective*+erint
Active;	Infinitive;		Perfect;		*Perfective*+isse

Table A–7: The subsidiary paradigm of Perfective forms

Non-finite Forms I

Stem+ndī: active ∧ gerund ∧ genitive

where *Stem* $\wedge_s$ *St*+*v*,

v $\wedge_s$ Vowel

Active;	Gerund;	Dative		*Stem*+ndō
Active;	Gerund;	Accusative		*Stem*+ndum
Active;	Gerund;	Ablative		*Stem*+ndō
Active;	Participle;	Present;	Nominative	*Infinitive*+ns
Active;	Participle;	Present;	Genitive	*Stem*+ntis
Passive;	Gerund			*Stem*+ndus ...

Table A–8: The subsidiary paradigm of "gerundive" forms

Non-finite Forms II

Supine+tum: active ∧ supine ∧ accusative

Active;	Infinitive;	Future	***Supine*+tūrum ...**
Active;	Supine;	Ablative	***Supine*+tū**
Active;	Participle;	Future	***Supine*+tūrus ...**
Passive;	Infinitive;	Perfect	***Supine*+tum ...**
Passive;	Participle		***Supine*+tus ...**

Table A–9: The subsidiary paradigm of "supine" forms

A.3 Less general paradigms

We may now turn to the description of paradigms that are more specific than those shown in the previous section. In particular we will use a classification by the stem-theme alternation in order to describe forms which deviate from those predicted by the system shown above.

Traditional analyses recognize four distinct thematic vowels, ā, ē, e and ī, associated with the First, Second, Third and Fourth conjugations respectively. In our treatment, as we have already described the behaviour of Second Conjugation forms, we need only make further statements about the irregular behaviour associated with the thematic vowels ā, e and ī. As we shall see below, many aspects of the Third and Fourth conjugation morphology can be conflated.

A.3.1 The thematic vowel ā

The irregularities shown by verbs such as *amāre* are limited primarily to the forms described in Table A–1 above.

Thematic vowel ā

Infinitive+re:verb where

STA(*Infinitive*, *Stem*)

am+ā $\wedge_s$ *Infinitive*,

$Subj_1$ $\wedge_s$ *am*+e,

$Subj_2$ $\wedge_s$ *am*+ē

Active;	Present;	Indicative;	Singular;	1	*am*+ō
Active;	Present;	Indicative;	Singular;	3	*Stem*+t
Active;	Present;	Subjunctive;	Singular;	1	$Subj_1$+m
Active;	Present;	Subjunctive;	Singular;	2	$Subj_2$+s
Active;	Present;	Subjunctive;	Singular;	3	$Subj_1$+t
Active;	Present;	Subjunctive;	Plural;	1	$Subj_2$+mus
Active;	Present;	Subjunctive;	Plural;	2	$Subj_2$+tis
Active;	Present;	Subjunctive;	Plural;	3	$Subj_1$+nt
Passive;	Present;	Indicative;	Singular;	1	*am*+or
Passive;	Present;	Subjunctive;	Singular;	1	$Subj_1$+r
Passive;	Present;	Subjunctive;	Singular;	2	$Subj_2$+(ris $\vee$ re)
Passive;	Present;	Subjunctive;	Singular;	3	$Subj_2$+tur
Passive;	Present;	Subjunctive;	Plural;	1	$Subj_2$+mur
Passive;	Present;	Subjunctive;	Plural;	2	$Subj_2$+minī
Passive;	Present;	Subjunctive;	Plural;	3	$Subj_1$+ntur

Table A–10: Irregular forms associated with the thematic vowel ā

A.3.2 The stem vowel i

In place of a description of an archetypal Fourth Conjugation verb such as *audīre*, I give a paradigm which enables us to generalize over the behaviour of verbs like *audīre* and those like *capere* which are usually assigned to the Third Conjugation. These verbs show comparable patterning over many parts of the paradigm, to do with the preservation of the stem vowel in imperfect forms, the introduction of the vowels ē and e in the future and a set of future endings which differ from those found in the First and Second Conjugations.

Stem vowel i

Infinitive+re:verb where

STA(*Infinitive*, *Stem*)

Stem $\wedge_s$ x+i,

uStem $\wedge_s$ *Stem*+u,

eStem $\wedge_s$ *Stem*+e,

ēStem $\wedge_s$ *Stem*+ē

Active;	Present;	Indicative;	Plural;	3	'*uStem*+nt'
Active;	Imperfect;	Indicative;	Singular;	1	'*ēStem*+bam'
Active;	Future;		Singular;	1	'*Stem*+am'
Active;	Future;		Singular;	2	'*ēStem*+s'
Active;	Future;		Singular;	3	'*eStem*+t'
Active;	Future;		Plural;	1	'*ēStem*+mus'
Active;	Future;		Plural;	2	'*ēStem*+tis'
Active;	Future;		Plural;	3	'*eStem*+nt'
Active;	Future;	Imperative;	Plural;	3	'*uStem*+ntō'
Active;	Gerund;	Genitive;			'*eStem*+ndī'
Passive;	Present;	Indicative;	Plural;	3	'*uStem*+ntur'
Passive;	Future;		Singular;	1	'*Stem*+ar'
Passive;	Future;		Singular;	2	'*ēStem*+(ris ∨ re)'
Passive;	Future;		Singular;	3	'*ēStem*+tur'
Passive;	Future;		Plural;	1	'*ēStem*+mur'
Passive;	Future;		Plural;	2	'*ēStem*+minī'
Passive;	Future;		Plural;	3	'*eStem*+ntur'
Passive;	Future;	Imperative;	Plural;	3	'*uStem*+ntor'

Table A–11: Irregular forms associated with the stem vowel i

A.3.3 The thematic vowel e

We have seen how a large part of the variation witnessed in the traditional conjugations may be reduced to the statements shown above. It now remains to describe the behaviour of the verbs traditionally assigned to the Third Conjugation with the "weak" vowel "e". These cover the appearance of short vowels in part of the active present paradigms, some irregularity over the form of the thematic vowel in the imperfect and in the supine formations.

Stem vowel i

Infinitive+re:verb where

STA(*Infinitive*, *Stem*)

Infinitive $\wedge_s$ x+e

Active;	Present;	Indicative;	Singular;	1	x+ō
Active;	Present;	Indicative;	Singular;	2	*Stem*+t
Active;	Present;	Indicative;	Plural;	1	*Stem*+mus
Active;	Present;	Indicative;	Plural;	2	*Stem*+tis
Active;	Present;	Indicative;	Plural;	3	x+unt

Table A–12: Irregular forms associated with the stem vowel i

Appendix B

A Computational Interpretation of Paradigmatic Morphology

A subpart of the system described in Sections 3.1.1 and 3.1.1 has been implemented in PROLOG and is described in detail in Calder *et al* (1989). The string unification algorithm was implemented by Mike Reape, developing work reported in Siekmann (1975), and is described in G. G. Bès (ed.) Technical Documentation of the ACORD Project, Laboratoires de Marcoussis. The system allows the expression of paradigms, character classes, finite negative and disjunctive constraints on strings, lexical rules and lexical entries. The important restrictions we may identify are as follows:

- Only non-composite lexical rules (see (180)) may be used in paradigms;
- Morphosyntactic properties are treated as templates (Shieber *et al* 1983);
- The set of items defined by a lexicon is finite.

The last restriction allows the generation of lexical items *off-line*.

Subsumption relations between paradigms are determined by an initial compilation. Items are generated using the definition of derivability given in Section 3.1.1. PROLOG's backtracking mechanism is used to enumerate lexical entries, which are then compared with the defined paradigms. In the case where a paradigm subsumes the lexical entry in question, all the paradigms that the first subsumes are then examined to verify that the Elsewhere Condition is obeyed. If the condition is obeyed, the lexical entry is unified with the paradigmatic word and a note made of all the derived forms that result from this unification. The routine is then called recursively, with each derived form as the lexical item to be generated from. Vacuous applications of paradigms, i.e. where one or more cycles through this process result in the generation of an item which subsumes the initial item, are catered for in a manner similar to the *subsumption check* in chart parsing. Before a derived form is noted a check is made to see whether the derived item is more general than some other derived item. If so, the process of derivation fails and backtracking will result in some other item being considered as a possible source of derivation.

This routine will generate the closure of the lexicon and the derived items may be used in conjunction with some other processor for the analysis of sentences containing those items.